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THE NITRATE DEPOSITS OF CHILE

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LOCATION OF THE NITRATE REGIONS

The nitrate deposits of Chile are in the northern part of that country, in the region lying between about 19° and 26° south latitude, and mostly in the provinces of Tarapacá and Antofagasta. Some more or less isolated deposits have been found both north and south of these limits, but, as yet, have not proved of very great extent.[1] The Tarapacá region has been worked for a longer time, and at present supplies more nitrate than the Antofagasta region, but the latter is an important producer and has great future possibilities.

[1] Many changes have occurred in the last thirty years in the boundaries separating Chile, Peru, and Bolivia; and even provinces which bear the same names now as they did then may have different boundaries, so that different accounts of this region written at different times necessarily conflict in statements of boundaries and names. The data in the present paper are based on the boundaries of states and provinces as they now exist.

The nitrate deposits are found at intervals in an arid region known as the pampa, which runs north and south in a long narrow belt for almost five hundred miles between the Andes on the east and the Coast Range on the west, and from a few miles to over one hundred miles inland.

During the year 1907 the writer visited some of the nitrate regions of northern Chile, and the present paper embodies his investigations there. The remarks apply mostly to the Tarapacá region, unless otherwise stated, as that was the only part of the field carefully studied. There is, however, much similarity in many of the features of the nitrate deposits in both Tarapacá and Antofagasta, though in some respects they differ considerably.

HISTORY OF THE NITRATE MINING INDUSTRY

The nitrate deposits of Chile have probably been known from very ancient times, but the extensive mining and utilization of them is a comparatively modern industry. During the wars for independence which the countries on the west coast of South America waged against Spain in the early part of the nineteenth century, the nitrates are said to have been utilized to make niter for gunpowder. The first operations to handle nitrate on any considerable scale, however, are said to have been started by a Frenchman named Hector Bacque, at La Noria, in Tarapacá, about 1826.[1] This enterprise was followed by a number of others, and in the next fifty years, many similar operations were started by Europeans, Americans, and Chileans.

The early enterprises were all in what is now the province of Tarapacá, a region which at that time belonged to Peru, and which was supposed to be the only part of this coast that contained nitrate; but as the industry grew and began to attract more general notice, search was made for nitrate elsewhere. The result was the discovery of deposits in the province of Antofagasta, lying south of Peruvian territory, and active mining operations were soon started there. At this time, the northern part of what is now Antofagasta belonged to Bolivia and the southern part to Chile. The Chilean government, recognizing the importance of the new discoveries, sent out a commission to investigate the occurrence of nitrate in Chilean

[1] G. F. Scott Elliot, *Chile*, p. 259.

territory. The report of this commission was published by the government and was printed in English, in London, in 1878. It shows that at that time active mining was going on both in Bolivia and in the adjoining Chilean territory. In both regions, Chilean capital and Chilean labor were employed to a large extent.

As the industry grew, Bolivia imposed an export tax on the nitrate shipped from her territory, which Chile considered inconsistent with certain treaty rights existing between the two countries. Chile protested against the injury done by the tax to her citizens engaged in the industry in Bolivian territory, but Bolivia continued the tax and war ensued in 1879. Peru was in alliance with Bolivia at that time and hence became involved in the fight with Chile. The war lasted until 1883 when peace was declared. Chile had been victorious on all sides, and after the war she annexed the two southern provinces of Peru, known as Tacna and Tarapacá, and the Bolivian province of Antofagasta, thus adding not only several hundred miles to the northern extension of her possessions, but also gaining control of all the known nitrate districts of the west coast of South America.

After the close of the war, the nitrate industry became much more active than formerly. New capital poured into the country and the deposits were rapidly developed. Mr. G. B. Chase, of the United States, and Colonel J. T. North, of England, were among the most active foreign operators, while the Chileans themselves were very energetic in developing the region. The Germans also have acquired large interests in the nitrate fields and are active operators, but the English companies are by far the most numerous of all. Though Americans were among the pioneers in the industry, their operations at present are small compared with those of the English, Germans, and Chileans.

NATURAL FEATURES OF THE NITRATE REGIONS

Chile extends along the west coast of South America in a long narrow belt from Peru southward to Cape Horn, a distance of almost 3,000 miles. In width it varies from less than 100 miles to rarely over 200 miles. It is essentially a mountainous region, being occupied on the east by the main range of the Andes, and on the west by the Coast Range. The Andes rise in rugged peaks to altitudes of from

10,000 to over 20,000 feet, while the Coast Range is lower, from 3,000 to 7,000 feet, though sometimes more. The Coast Range is often characterized by rounded summits and smooth slopes, in marked contrast with the bold angular contour of the Andes. In some places the Coast Range is prominently marked, while in others it is little more than the escarpment of an interior plateau as it breaks off to the sea.

Both the Andes and Coast Range follow a general north-and-south course, and between them is an intervening belt of lower country known as the central or longitudinal valley. This so-called valley, however, is not a single continuous drainage area bordered by two mountain ranges as might be supposed, but is a series of elevated basins, forming rolling plains or plateaus, more or less separated by transverse ranges, and draining independently of each other into the Pacific Ocean. In some places the mountains on the east and west approach so closely to each other that their foothills blend together, almost obliterating the intervening basin region; in other places they separate, and the basin region broadens out to many miles in width (see map, Fig. 1).

In northern Chile this basin region is especially well marked in the provinces of Tarapacá, Antofagasta, and northern Atacama. It is here an elevated arid country and includes the Tamarugal Desert on the north and the Desert of Atacama on the south.[1] It is of a generally flat or undulating character, from less than 2,500 feet to over twice that height above the sea, and studded with small, rounded hills, some of which rise considerably higher than the surrounding plateau (see Fig. 2). Its surface is dry and sandy, very few streams intersect its parched expanse, and vegetation is almost totally absent.[2] This region is known as the *pampa*, a term applied somewhat indiscriminately not only to the whole arid region, but

[1] The Tamarugal Desert includes most of the interior basin region of the province of Tarapacá and the northern part of the province of Antofagasta. The Desert of Atacama includes the southern part of Antofagasta and the northern part of the province of Atacama.

[2] Farther south, in central Chile, the basin or valley region becomes a rich fertile country under the influence of the plentiful rainfall there; and still farther south, in southern Chile, where the basin region is more or less submerged in the ocean, the rainfall increases so much as to make one of the wettest parts of the world; but in this northern section the dry desert character of the country is its distinguishing feature.

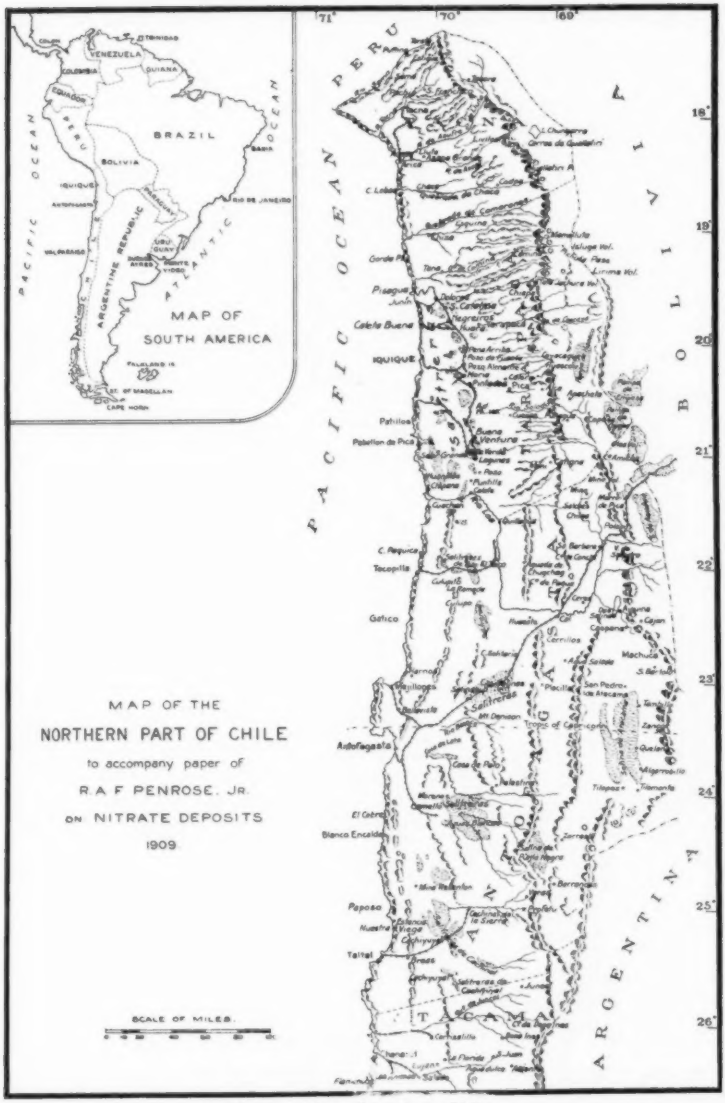

FIG. 1.—Map of northern Chile.

also to special parts of it, either large or small. Thus the term Tamarugal Pampa applies to a large part of the basin of Tarapacá and northern Antofagasta, while the term Tarapacá Pampa applies only to the part of the basin region in the province of that name; and the terms Huara Pampa, El Toco Pampa, Taltal Pampa, and many others apply to purely local districts.

Rain is very rare in the pampa, frequently three or four years, and sometimes eight or ten years of unbroken drought occurring. The Coast Range in this part of Chile is almost as dry as the pampa, though fogs from the ocean are common, and their moistening influence encourages the growth of a little grass and a few cacti on the tops of the hills. Even the fogs, however, rarely reach the pampa. Many streams flow westward from the Andes, but most of them rapidly evaporate or sink below the surface when they come to the pampa, and hence a map of the region shows them suddenly terminating at the foot of the mountains (see map, Fig. 1). The waters that sink continue westward underground, occasionally rising near enough to the surface to form oases in the desert, and then disappearing again. In times of high water, some streams reach the sea on the surface, but only very few do so perennially. Sometimes during seasons of great rises in the rivers of the Andes, the pampa is flooded over large areas. Such occurrences are rare, though some have been recorded, and evidence of them is seen in the dry gullies running across the pampa and in the local accumulations of drift wood from the Andes. In past ages these floods were probably more frequent than now, but the normal condition of the pampa today is one of great aridity. The very presence of nitrate deposits is evidence of the extreme dryness of the region, for nitrate is easily soluble, and water would soon dissolve it and carry it away. The only vegetation is in a few isolated spots where underground streams rise near enough to the surface to support the growth of a little grass or a few stunted trees. Elsewhere the pampa is a sandy desert, from which an impalpable dust rises in blinding clouds with the slightest wind and where the drifting sands form immense dunes similar to those seen on the coast.

The surface of the pampa is composed mostly of sand, clay, and gravel, with masses of more or less rounded rock fragments scattered

FIG. 2.—Typical view in the pampa of the province of Tarapacá, Chile, showing the nitrate deposits near the base of the low hills, and the Coast Range in the far distance.

over it, and frequent deposits of saline materials. Through these loose materials frequently protrude isolated hills and knolls of stratified and igneous rocks similar in nature to many of the rocks found in the adjoining mountain ranges; and doubtless rocks of like character underlie the loose sediments of the pampa. The surface materials of the pampa are probably of post-Tertiary age and represent an old sea bottom formed by the deposition of sediments in a now extinct inland sea, or a series of lakes, which once extended from the Andes to the Coast Range, over the whole extent of what is now the pampa.

The Coast Range bordering the pampa on the west is composed of a variety of rocks varying greatly in different places from Tarapacá southward through Antofagasta and Atacama. Old crystalline rocks, including gneisses, granites, etc., frequently occur. Stratified rocks of probably both Paleozoic and Mesozoic ages, including sandstones, limestones, and shales, are abundant in many places, and are much folded, contorted, and broken. They are intersected in many places by igneous intrusions. As we cross the pampa and approach the Andes, both stratified and igneous rocks again appear through the loose sediments; and in the high Andes immense areas of late volcanic flows are found.

MODE OF OCCURRENCE OF THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The pampa region has a general slope from east to west, that is, from the foot of the Andes to the foot of the Coast Range, though it is so gradual as to be often unnoticeable to the eye. As a result of this slope the lowest part of the pampa is along its western border, where it abuts against the Coast Range foothills. It is along this zone that the nitrate deposits occur, and in the province of Tarapacá they occupy a narrow north-and-south belt following this position for over one hundred miles. The surface of the pampa is here almost always impregnated with more or less saline matter, which sometimes becomes so abundant as to form beds several or many feet in thickness. These are practically superficial deposits, though they are sometimes capped by earthy materials for some feet in depth. Their surface, when exposed, often presents a rough and more or less

leached appearance, due to the action of the rains and floods which at rare periods visit the pampa (see Fig. 3). Sink holes, due to the same cause, are not infrequent. Most of the deposits consist of common salt (sodium chloride) or of nitrate (sodium nitrate), or of both mixed together; while other saline materials occur more sparingly. The salt beds are called by the Chilean *salares* and the nitrate beds, *salitreras*. The material composing the nitrate beds is known as *caliche*.

Though both common salt and nitrate occur in very large quantities, the former is by far the more abundant, and covers immense flats for many square miles in area along the western edge of the pampa. Sometimes it is in comparatively pure beds, sometimes it is mixed with clay, sand, and gravel, and sometimes it only impregnates the surface of the pampa. These salt beds have not yet been extensively explored, but they probably vary from a mere crust to several or even many feet in thickness. The salt is not much used, though a little is obtained for local consumption and is refined by dissolving and evaporating the solution.

The nitrate deposits, though less extensive than the common salt deposits, are far more important commercially. Like them, they occur in the low zone along the western edge of the pampa, but while the salt flats are usually in the very bottoms of the basins, the nitrate deposits are usually on a little higher ground. Sometimes the nitrate deposits also occupy the bottoms of the basins, but their typical position is on the lower slopes of the hills and ridges, forming terraces or benches around the salt flats, and from a few feet to perhaps one hundred feet or more above them. Sometimes there may be nitrate upon the slopes and no salt in the flats, and sometimes there may be salt in the flats and no nitrate on the slopes, while sometimes the deposits of the two materials are more or less indiscriminately mixed or may underlie or overlie each other; but in many cases we find them both occupying the respective typical positions just mentioned. The slopes on which the nitrate often occurs rise at low angles and are sometimes scarcely distinguishable from the surrounding flat country.

The nitrate deposits are of very variable thickness even over small areas, and in one spot there may be several feet of the material, while within a few yards there may be only a few inches, or none at all.

FIG. 3.—View in the pampa of the province of Tarapacá, Chile, showing characteristic surface features of the salt and nitrate deposits.

A thickness of from 1 to 1½ feet is common, of 2 to 3 feet is less so, but not unusual, and of 4 to 6 feet is very unusual. Where the surface of a deposit is not too heavily covered with earthy materials, it often has a moist appearance due to the deliquescent character of the nitrate or perhaps to the presence of calcium chloride.

The nitrate deposits are usually covered by a capping composed of sand, clay, gravel, and rock fragments, from a few inches to many feet in thickness. In a few places this capping is absent and the nitrate is covered only by a thin coating of desert dust, but usually the overlying material is from 2 to 20 feet in thickness and sometimes, though rarely, 30 to 40 feet. This capping is called *costra* and is generally more or less indurated; the usual condition being alternating layers or patches of harder and softer material, and an extreme condition being that of a hard mass like a breccia or conglomerate, in which the cementing material is nitrate and other saline and earthy substances. The rock fragments are angular or partly rounded and vary from the size of grains of wheat to masses of a foot or more in diameter, pieces from a half-inch to 3 inches in diameter being the most common. The fragments consist of limestone, shale, sandstone, igneous rocks, etc., the preponderance of one or the other varying in different places. They seem to some extent to vary in character according to the nature of the rocks *in situ* in the neighborhood, and seem to have been derived largely from the slopes of the Coast Range hills and from the small knobs protruding up through the pampa. The costra is often overlaid by from a few inches to a few feet of loose, wind-drifted material called *chuca*.

In some places there is a sharp line of demarkation between the costra and the nitrate; in others they seem to blend into each other. In fact, they often seem to represent one and the same deposit, rich in nitrate at the base and poor in nitrate above. The smaller quantity of nitrate in the costra than below may possibly be due to impoverishment by leaching during the rare periods of rainfall or flood. In a few of the mines where the rich part has been exhausted, the costra has been worked as a source of nitrate. Underlying the nitrate is an earthy material of a brown or buff color, generally soft and powdery though sometimes sandy, gravelly, or indurated, called *coba*. Below

the coba is the great series of interbedded sands, clays, and gravels which underlie the broad expanse of the pampa.

A general section of the nitrate deposits in Tarapacá, therefore, would show the following succession of formations:

"Chuca" (loose, wind-blown material, dust, sand, gravel, etc.)....0–several feet
"Costra" (capping of the nitrate beds).....0–20 or even 30 or 40 feet
"Caliche" (crude nitrate).....0–6 feet
"Coba" (earthy floor of nitrate beds).....Indefinite (perhaps a few feet)
Stratified sands, clays, and gravels.....To great depths

In a few places the nitrate occurs as a fringe around the edges of the isolated knobs of rock that rise up through the pampa, and rests either on the solid rock or on the detritus of the hillside, but its usual occurrence is overlying the earthy materials described above.

MATERIALS COMPOSING THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The nitrate occurs in the form of sodium nitrate with the formula $NaNO_3$, though very small quantities of other nitrates are sometimes found with it. It generally occurs as a translucent mass, sometimes in a coarsely or minutely crystalline aggregate of rhombohedra; sometimes in a stalactitic or mammillary form, or as an efflorescence or incrustation. When pure, it is of a white color, but is often yellow, red, brown, or purple from impurities. Frequently it is much streaked or spotted a dirty brown color due to sand or clay, and sometimes it is so mixed with earthy matter as to have a chocolate-brown appearance throughout. The crude material, as already stated, is known by the Chileans as caliche. Its mineralogical name is soda niter or nitratine. Sometimes it is called cubic niter or cubic saltpeter, because on casual inspection its rhombohedral crystals seem closely to approach the form of cubes. Commercially it is often known as Chile saltpeter, as distinguished from plain saltpeter, or niter, which is potassium nitrate.

The nitrate deposits are never composed of perfectly pure sodium nitrate, that material forming usually only from a small percentage up to rarely as much as 70 per cent. of the whole mass. Crude nitrate containing 25 per cent. of sodium nitrate is considered a fair grade of raw material, one containing 50 per cent. is considered high,

and one containing 60 or 70 per cent. is very rare, though of course in selected specimens even 90 per cent. or more of sodium nitrate may be found. The impurities are sand, clay, gravel, and rock fragments, with a very variable admixture of saline materials. The rock fragments are similar to those already described in the costra, overlying the nitrate. In some places they are scattered only sparingly through the deposits; in others they are so numerous as to form a breccia or conglomerate with the nitrate as a matrix.

The saline impurities in the nitrate are mostly common salt (sodium chloride), with variable amounts of sodium sulphate (Glauber salts) and calcium sulphate, the latter often occurring as crystalline gypsum and perhaps also as anhydrite. In addition, there occur sodium and calcium borates, as well as carbonate, chloride, and other salts of calcium, and various salts of aluminum, magnesium, potassium, ammonium, and a small but very constant quantity of sodium iodate. Bromine compounds, together with other materials in small quantities, are sometimes, though more rarely, present. The common salt (sodium chloride) occurs in varying amounts in all the nitrate deposits, sometimes in very large quantities, and we find all gradations in admixture from deposits composed mostly of nitrate to deposits composed mostly of salt. The other saline materials are in comparatively small amounts, though in special cases some of them may be more abundant than the common salt.

The following analyses represent the composition of samples of crude nitrate (caliche) from different localities. The analyses were made in Chile by Mr. D. G. Buchanan, chemist of the Alianza Company, and were kindly sent to the writer by Mr. J. F. Comber, manager of the North Lagunas Company.

The saline impurities in the crude nitrate are generally purely mechanical admixtures, like the salt, but sometimes they are associated with the nitrate in certain proportional relations, forming distinct minerals. Thus we have darapskite and nitroglauberite, both minerals consisting of hydrous nitrates and sulphates of sodium. Moreover, both the nitrogen and the iodine occur in small quantities in other combinations than with sodium. Small amounts of potassium nitrate are often found, while calcium nitrate (nitrocalcite) and barium nitrate (nitrobarite) as well as calcium iodate (lautarite) and

a calcium iodo-chromate (dietzeite) also occur. These and other rare combinations that are found in the region are, however, in small quantities and are only mineralogical curiosities.

The iodine in the crude nitrate is an important material on account of its commercial value. It is a very constant ingredient in the deposits, though in minute quantities, generally only a fraction of 1 per cent., and occurs usually in the form of sodium iodate, though a little sodium iodide has also been found. Sometimes the iodine is

ANALYSES OF CRUDE NITRATE (CALICHE) FROM CHILE

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sodium nitrate	28.54	53.50	41.12	61.97	22.73	24.90	27.08
Potassium nitrate	trace	17.25	3.43	5.15	1.65	2.50	1.34
Sodium chloride	17.20	21.28	3.58	27.55	41.90	24.50	8.95
Calcium chloride	.....	.....	.....	.....	.....	.....	5.25
Magnesium chloride	.....	.....	.....	.....	.....	.....	0.18
Potassium perchlorate	trace	0.78	0.75	0.21	trace	trace	trace
Sodium sulphate	5.40	1.93	trace	2.13	0.94	6.50	none
Magnesium sulphate	3.43	1.35	10.05	0.15	3.13	6.50	none
Calcium sulphate	2.67	0.48	3.86	0.41	4.80	4.50	2.89
Sodium bi-borate	0.49	0.56	0.20	0.43	0.53	0.15	0.52
Sodium iodide	0.047	.....	.....	.....	.....	.....	.....
Sodium iodate	0.043	0.01	0.05	0.94	0.07	0.054	0.08
Ammonium salts	trace	trace	trace	trace	trace	trace	trace
Sodium chromate	.....	trace	.....	distinct traces	trace	.....	.....
Insoluble matter	40.30	2.07	31.86	0.39	22.50	28.40	47.34
Combined water, etc.	1.88	0.79	5.00	0.07	1.75	2.00	6.37
	100.00	100.00	100.00	100.00	100.00	100.004	100.00
Total nitrates calculated as sodium nitrate	28.54	68.00	44.02	66.29	24.11	27.00	28.20
Total chlorides calculated as sodium chloride	17.20	21.28	3.58	27.55	41.90	24.50	14.70
Total iodine	0.067	0.0064	0.036	0.604	0.045	0.035	0.051

more abundant in the salt deposits than in the nitrate deposits, but the market demand is supplied by what is obtained as a by-product in refining the nitrate, and hence the salt is not worked for iodine. Borates occur in many places throughout the arid region of the pampa, mostly in the form of the hydrous borate of sodium and calcium known as ulexite or boronatrocalcite, or in the form of the hydrous calcium borate known as colemanite. In places these materials have been worked to a very considerable extent. Some sodium bi-borate is also found. Sodium sulphate occurs in large deposits

in parts of the pampa, especially in Antofagasta, but is not worked on account of the limited demand for it. There are many materials in the pampa, such as potassium salts, etc., which would be of great value if found in quantities, but, so far as yet known, they occur too sparingly to be of any considerable commercial importance.

To summarize, it may be said that the commercial products of the pampa are mostly sodium nitrate, with comparatively small, but commercially very important, quantities of iodine; while common salt is obtained on a small scale for local use, and borates have been produced in varying quantities at different times, often in very important amounts. The production, however, of all the other saline materials in the pampa is insignificant in importance compared with that of sodium nitrate.

OTHER NITRATE REGIONS IN CHILE

As already stated, almost all the nitratè of Chile is in the great arid basin lying between the Andes and the Coast Ranges, in the provinces of Tarapacá and Antofagasta. South of the nitrate fields of Tarapacá, already described, the main pampa region extends through the province of Antofagasta and here several large nitrate fields occur. A number of transverse ridges, or ranges of hills, intersect this region, forming more or less separated basins, and it is in these that the nitrate occurs. The different basins are designated as different pampas, but all of them are simply parts of the general pampa region.

The El Toco Pampa is in the northern part of the province of Antofagasta, and here large deposits of nitrate are actively worked. The refined product is shipped from Tocopilla, a seaport about 120 odd miles south of Iquique, and connected with the nitrate district by a railway. Farther south in the same province are the Antofagasta Pampa and the Aguas Blancas Pampa. Both are large producers of nitrate, and are connected by railway with the port of Antofagasta, which is the shipping-point for the nitrate from these districts and is an important city of about 20,000 people. Recently also a new port called Mejillones, a few miles north of the port of Antofagasta, has been improved and connected with the railway running into the nitrate fields, in order to facilitate shipments. Still farther south,

in the extreme southern part of the province of Antofagasta, is the Taltal or Cachinal Pampa, where large quantities of nitrate are also produced. A railway connects this district with the coast at Taltal, which is a prosperous seaport in the southern part of the province of Antofagasta and the shipping-point for the Taltal district.

Though most of the nitrate deposits of Chile are in the provinces of Tarapacá and Antofagasta, yet some have been found to the north and south of these limits. As yet, however, they have not become of great importance. In the province of Tacna, to the north of the province of Tarapacá, several small pampas represent a northerly continuation of the general pampa region, and a few small nitrate deposits have been found there. South of the province of Antofagasta, isolated nitrate deposits have been reported in places in the northern part of the province of Atacama, but the extent of the deposits is not yet well defined.

ORIGIN OF THE NITRATE DEPOSITS OF CHILE

The discussion of the origin of the nitrates of Chile involves chiefly the source of the nitrogen, and many suggestions have been advanced to explain its presence, but its derivation from organic matter, and especially from guano, seems the most probable hypothesis. Among some of the other hypotheses that have been suggested may be mentioned the following:

It is a well-known fact that electric storms have the power of causing the oxidation of the nitrogen of the air with the formation of nitric acid. It has been suggested by some that such storms in the Andes have generated nitric acid, which, coming in contact with the limestone found in places in the mountains, has formed calcium nitrate; and that this has in turn been converted to sodium nitrate by contact with sodium salts found in the pampa region.

It has also been suggested that the nitrogen of the nitrates was derived from nitrogenous fumes from volcanoes in the Andes.

A. Pissis[1] quotes authority to show that alkaline carbonates have the power "of transforming atmospheric nitrogen into nitric acid in the presence of other oxidizable matters." He points out that the decay of feldspar in the rocks of the region has supplied a source

[1] *Nitrate and Guano Deposits in the Desert of Atacama*, London, 1878, p. 16.

of alkaline carbonates, that the protoxide compounds of iron, which are common in the rocks of the pampa, are easily oxidized under ordinary conditions forming peroxide compounds of iron, and he thinks that the alkaline carbonates, under such environment, have caused the oxidation of the nitrogen of the air with the ultimate formation of nitrates.

David Forbes[1] thinks that the nitrates were derived from the decay of vegetation around and in salt water swamps and lagoons, which he believes once occupied the site of the present pampa. A certain amount of nitrogenous matter might be derived in such a manner, and this subject will be discussed again later on.

It seems, however, as if a source of nitrogen more abundant and ready than any of those mentioned might have existed in the immense accumulations of guano which for ages have been characteristic of this coast, and this suggestion has been offered by a number of other writers. Incidentally it may be stated that in many parts of the world, especially in warm regions, nitrates are found in small deposits in caves, in association with bat guano, and that the source of the nitrogen from this guano is very generally recognized.[2]

It is well known that the part of the coast of Chile where the nitrates occur has been gradually rising in recent geologic times, and that the pampa region already described was once a part of the ocean bottom. During this elevation, as the region gradually rose up to, and then above, the ocean level, it probably passed first through the condition of an open bay or gulf, then became more and more separated from the ocean, and finally, when raised completely above it, became a more or less inclosed interior basin occupied by an inland sea, or a series of basins occupied by salt lakes, lying between the Andes and the Coast Range. Guano beds were doubtless deposited along the borders of these waters, just as they are now deposited on the neighboring shores of the Pacific.

Guano consists largely of nitrogenous materials, phosphates, and water, with other substances in smaller quantities. The nitroge-

[1] "On the Geology of Bolivia and Peru," *Quarterly Journal of the Geological Society of London*, Vol. XVII (1860–61), pp. 13–16.

[2] A. Muntz et V. Marcano, *Académie des Sciences, Comptes Rendus*, Vol. CI (1885), pp. 65–68. See also A. Muntz, *ibid.*, pp. 1265–67.

nous materials consist mostly of ammonium salts, especially of urate of ammonium, and other urates, together with guanine[1] and variable quantities of nitrates and nitrites, as well as with various other organic products resulting from decayed animal matter. It is a well-known fact that, under suitable conditions, the nitrogen of all these materials that are not already in the form of nitrates, passes eventually into that form through the agency of certain microscopic organisms (bacteria). These bacteria are of many different kinds, and different ones act at different stages in the transition. The action, when other conditions are favorable, goes on most efficiently in the presence of alkalies, or of alkaline earths like calcium carbonate, etc., which are abundant in the pampa region.

It seems probable that the nitrates of Chile were mostly produced in this way from nitrogenous animal matter of old guano beds which once lined the waters of the interior basin, and which have long since disappeared under the influence of erosion. The nitrates were probably carried down into the waters of the basin and became mixed with the other saline materials already there. The waters probably began to diminish in volume shortly after their separation from the sea, for though they received the drainage of the surrounding land, this was not enough to compensate for the loss by evaporation. The evidence tends to show that the rainfall in those early days was more abundant in this region than at present, but it gradually grew less and its constant diminution doubtless hastened the process of desiccation.

Thus the waters gradually sank until they fell below the level of any outlet they may have had to the ocean, and then, the drainage being cut off, the materials in solution became more and more concentrated as desiccation progressed. These materials consisted of the original salts of the sea water, the nitrates and other salts from the guano beds, and other materials constantly carried down from the surrounding land. The concentration continued until the waters became saturated with saline materials, and then deposition began along the edges and on the bottom. Eventually the whole body of water disappeared and the dry desert pampa with its deposits of nitrates, common salt (sodium chloride), and other materials alone

[1] Guanine is an organic base containing nitrogen and having the formula $C_5H_5N_5O$.

remained. The occurrence of the nitrate in the form of sodium nitrate is probably due to the abundance of sodium salts in the region.

The occurrence of the nitrate and other saline deposits along the western edge of the pampa, where the latter is lowest in altitude, may be due to one or both of two causes:

1. The pampa, sloping as it does from east to west, gradually caused the last of the waters of the inland basin, as they evaporated, to collect along its western edge. If the nitrate in solution had not become sufficiently concentrated to cause deposition before that time, the deposits of course would be formed only on the west side.

2. If, however, deposition had begun while the waters still washed the slopes of the Andes, the greater rainfall there than on the west side of the pampa may have dissolved the nitrate from the east side and allowed it to be carried down into the loose soil of the pampa, or else over to the west side, where it was again deposited as the waters evaporated.

As against the hypothesis of the derivation of the nitrates of Chile from guano, the objection has been made that guano beds, and the remains of dead birds such as generally occur in them, are often notably absent in some of the nitrate districts. Very little guano is found with the Tarapacá nitrates, but in Antofagasta it does occur in the same region as some of the nitrate deposits. The scarcity of guano at present in some of the regions is easily explained, for the birds which formed it were essentially sea birds, dependent upon fish for food. As the waters of the inclosed basin gradually evaporated they became too saturated with saline matter for fish to live in them, so that the birds had to abandon their old haunts in the basin and seek other regions for their sustenance. Hence, though immense accumulations of guano had probably been formed, no new supply was maintained, and ample time has elapsed for the old guano to have been carried away, as already described, and for the bones, etc., to have disintegrated. The fact that guano is still abundant in parts of the nitrate regions of Antofagasta and not so in Tarapacá probably indicates that the birds left the latter region at an earlier date than the former, or that the conditions for its preservation were better in Antofagasta than Tarapacá.

The notable absence of seashells and remains of other marine

life in the nitrates of Tarapacá, may be explained in a manner similar to that suggested for the absence of guano, that is, the water became too heavily charged with saline matter for such life to exist, and the remnants of what had previously existed were gradually destroyed or were covered up by later pampa deposits.

If the nitrate was derived, as already described, from old guano beds long since disintegrated and eroded, then we might expect to find phosphates from the same source concentrated somewhere on the pampa; but such, so far as known, is not the case, though of course phosphates are found in the still existing later guano. Perhaps, however, phosphates from the old eroded guano may exist, and may not yet have been discovered, as the pampa has been but little studied outside its nitrate deposits. As the phosphates in guano are both soluble and insoluble, some of the former derived from the old guano may possibly have percolated into the limestone existing in parts of the region, forming insoluble calcium phosphate, such as occurs in coral formations in the West Indies and the South Sea Islands; while perhaps some of the insoluble phosphates resulting from the old guano may yet be found among the sediments of the sea bottom which now forms the pampa.

It is possible that in addition to the nitrate derived from guano, a small amount of it may have been derived from the decay of the marine and land vegetation of the interior basin. This decay would set free nitrogenous vegetable materials from which nitrates might have been formed, just as from guano. Nitrogen, however, is much more abundant in guano than in vegetable matter, and, therefore, the probability seems to be that guano was by far the more important source of the nitrates. Marine vegetation, however, probably played a most important part in supplying the iodine found in the region.

The source of the iodine in the nitrate and salt deposits of the pampa has been a much-discussed subject. Iodine is a constituent of many minerals and is found in many mineral springs, as well as in minute quantities in sea water. It also enters in small but appreciable quantities into the composition of certain marine plants and some sea animals. In fact before the iodine of Chile came into use, most of the iodine of commerce was extracted from

certain forms of seaweed or kelp. Iodine is taken up by such plants from the sea water and fixed in their tissues.

The iodine may, therefore, have come either from sources on the land or in the water or both. As yet no strong evidence has been produced to show that it came from the land. On the other hand, we have no definite evidence that it came from marine sources, but at the same time we know that the pampa was formerly probably covered by a body of sea water, at first connected with the open ocean and later cut off from it. During the time that it was more or less directly connected with the ocean an immense accumulation of iodine-bearing marine plants may have grown there, gradually collecting the iodine not only from the limited quantity of water represented by the arm of the sea in which the plants grew, but also from a constant fresh supply of sea water circulating in and out from the ocean, or dashed over a possible dividing barrier during storms and high tides. Possibly also similar marine plants from the open ocean may have come in with this sea water and accumulated, in a manner similar to that seen in many parts of the world today, thus augmenting the marine plants already growing there. After the region had been completely cut off from the ocean and desiccation had progressed sufficiently, this marine flora would decay and thus afford a great quantity of iodine. The simple evaporation of the water of the inclosed basin would of course account for some of the iodine, as this material is universally present in sea water, but in quantities so extremely minute that it seems necessary to suppose that the iodine of the pampa has been segregated from far larger quantities of water than those of the basin alone.

Hence, though the possibility of the source of the iodine from the decay of iodine-bearing minerals or springs on the land cannot be denied, yet the facts at hand suggest more strongly a source from marine plants.

As regards the borates found in the pampa, it may be said that, like the borates found under similar conditions in many other arid regions, they were probably derived mostly from the decay of boron-bearing minerals and from springs carrying boron compounds, such as are common in many mountainous regions, and especially those of igneous origin. Boron compounds occur also in sea water and

in some plants, but in quantities so extremely minute as to make such sources answerable for only a very small amount of the borates of the pampa. On the other hand, when we consider the vast areas of igneous rocks in the Andes and even in the Coast Range, the source mostly from boron-bearing minerals and springs seems very plausible. The boron materials from such sources were probably carried down into the waters of the inland basin, where they were concentrated and deposited in the same manner as the other saline materials.

In concluding the subject of the origin of the nitrates and other saline deposits of the pampa, it must be said that the present discussion is intended only as a most brief and general one. A vast amount of geological and chemical details must be worked out both in the field and the laboratory before the subject can be fully understood. The determination of the exact conditions of deposition and the various chemical transitions through which the saline materials have gone, require far more data than are at present available.

INDUSTRIAL FEATURES IN THE TARAPACÁ REGION

Mining and refining of nitrate.—Mining in the nitrate regions is done in surface openings. The capping of costra is thrown aside and the nitrate below mined and raised to the surface (see Figs. 4 and 5). The quantity of nitrate often varies greatly in different parts of a deposit and the change from rich spots to lean spots is often very abrupt, so that nitrate is usually worked in isolated pits or short trenches on the spots where it is richest, and not in long trenches running systematically through the deposit, as would be the most economical way if the deposits were uniform. Hence, most properties that have been extensively worked present the appearance of an upturned tract studded with numerous pits, some close together and some more or less separated. In some cases, where the capping of costra is hard and compact, or very thick, the miner finds it easier to go under it in search for nitrate than to remove it, and thus small underground workings in the form of caves have sometimes been formed, but these are the exception, and the usual mining is in open pits.

When the richest parts of a deposit have been exhausted, the miner

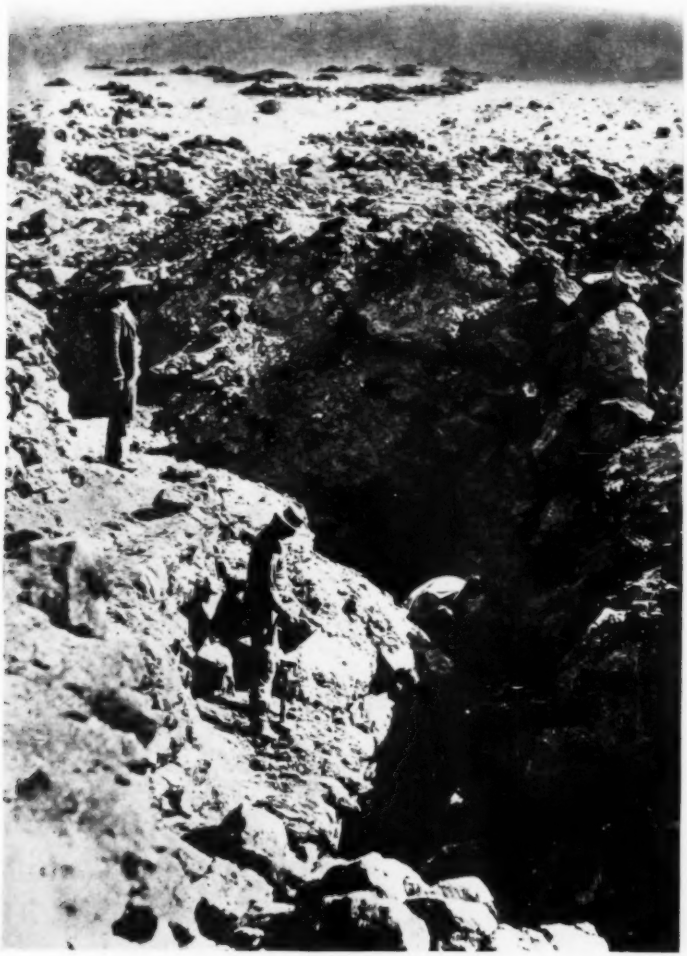

FIG. 4.—Nitrate mining in the province of Tarapacá, Chile.

often goes over the property again more carefully in search of what is left. In this way many properties have been worked over several times, and lower-grade material has been taken each time. In a few cases, even the costra, when it contains an unusual amount of nitrate, has been used after the purer parts of the deposits have been exhausted.

In the early days, only the richest of the deposits were worked, and only crude nitrate running as high as 40 or 50 per cent. in sodium nitrate was mined, but now much lower grades are worked, and the average of the crude material used in the Tarapacá region today would run, perhaps, below 25 per cent. in nitrate. Of course both richer and poorer material is also worked, and in certain places crude nitrate running even as low as 10 per cent. is utilized in admixture with higher-grade material.

The crude nitrate is hauled in carts or on tramways from the mines to the refineries, where it is coarsely crushed and the nitrate separated from the impurities by a process of leaching with hot water. The refined product usually contains about 95 per cent. of sodium nitrate, which is the standard of purity for the nitrate shipped from the district. Sometimes a still higher-grade product is made for special purposes. The nitrate is put in large sacks, and sent to the coast for shipment to various parts of the world. Sodium nitrate is deliquescent, so that when exposed to the moist air on board ships it cakes and the sacks stick together, often forming a solid mass which has to be taken out of the ships with picks.

The method used in extracting the nitrate is very crude, only from 60 to 70 per cent. of it being saved, and the average loss of nitrate in the Tarapacá region in refining is said to be about 35 per cent. Those in authority claim that under present conditions, the nitrate that is lost could not profitably be saved, but the time may come when the crude nitrate will show signs of exhaustion, and then probably less wasteful methods will be devised, and the loss will be cut down. At present, the supply of crude material is so vast that such economy has not been forced on the producers.

The iodine is obtained from the solution (mother liquor), after the nitrate has been taken out, by concentrating it and treating it with sodium sulphites, which precipitate a black powder consisting

mostly of iodine. This is then sublimed and condensed, when it is deposited in black scaly flakes of crystalline iodine.

FIG. 5.—Nitrate mining in the province of Tarapacá, Chile.

The water for the nitrate works is obtained mostly from wells in the pampa, and is often gotten in considerable quantities at depths

of from 50 to 100 feet. Some water is also obtained by piping from the foot of the Andes.

Companies, towns, cities, and railways.—The nitrate industry is carried on largely by companies, and the establishments at which their operations are conducted are known as *oficinas*. Among some of the best-known oficinas in Tarapacá are the Alianza, Agua Santa, Camiña, Josefina, La Granja, Central Lagunas, North Lagunas, South Lagunas, Puntunchara, Puntilla de Huara, Rosario de Huara, Ramírez, Santa Lucía, Santiago, Unión, and many others. In 1907 there were almost one hundred oficinas in the Tarapacá region and about one hundred and fifty in all Chile (see Fig. 6).

Many small towns have grown up on the Tarapacá Pampa as a result of the nitrate industry, among them being Dolores, Santa Catalina, Negreiros, Huara, Pozo Almonte, La Noria, Lagunas, Tapiga, San Antonio, etc. The oficinas that are not at any of the towns have become small communities in themselves, with large capacious buildings for the administration of the works, houses for the employees, stores, schools, etc.

The chief ports for the shipment of the nitrate of the province of Tarapacá are Iquique on the south and Pisaqua on the north, the former being by far the more important and the real headquarters of the nitrate trade of this province. They are both connected with the nitrate fields by railway. Iquique is a flourishing city of about 50,000 inhabitants (see Fig. 7), and Pisaqua has about 5,000. Smaller ports from which Tarapacá nitrate is shipped are Junín and Caleta Buena, both lying between Iquique and Pisaqua. Farther south, the seaports of Tocopilla, Antofagasta, Taltal, etc., are important shipping-points for the nitrates of the province of Antofagasta.

The Nitrate Railways Company (an English corporation) owns a line running inland from Iquique to the Tarapacá Pampa and then branching out through the nitrate fields. It intersects the pampa from Pisaqua on the north to Lagunas on the south, a distance in a straight line of over one hundred miles and much farther as the railroad goes, besides having many lateral branches, its aggregate length being about three hundred miles. Many of the nitrate works located to one side or the other of the railroad are connected with it by branch

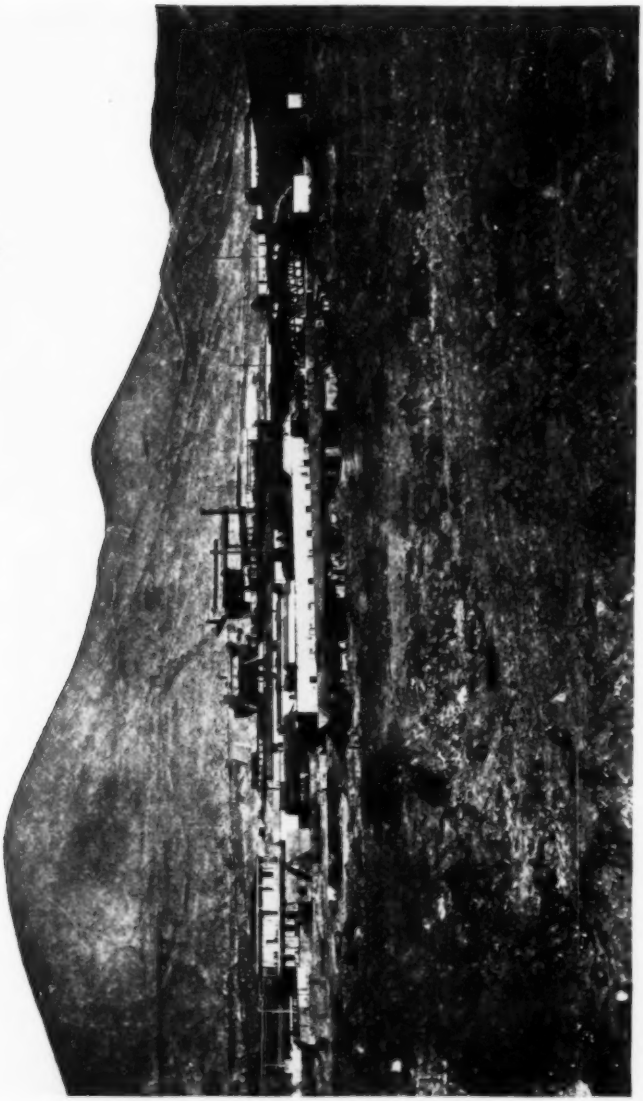

FIG. 6.—Nitrate works in the province of Tarapacá, Chile.

lines or by tramways worked by mules, and some of the nitrate companies have their own railways to the coast.

Nitrate production.—For a large part of the time in recent years, most of the large nitrate producers have been in a combination (Combinación Salitrera), which limits the output of refined nitrate and apportions to each company the amount that it may produce annually. This combination has been broken more than once by dissensions among the producers, and as late as March, 1909, after it had been in force for several years, it was again broken. Recent reports, however, are to the effect that strong efforts are being made to renew it. The object of the combination is to keep up the price of nitrate; and the production of iodine is controlled in the same way. The market for iodine is so limited that usually in a few months one company can produce enough to supply its allotment for several years. An organization is maintained to promote the use of nitrate, especially in agriculture, and agents are kept in all the large countries of the world. As a result, the consumption of nitrate is rapidly increasing, and the amount each company is allowed to produce increases correspondingly. The product goes largely to the United States and Europe, with smaller quantities to other countries.

In 1830 the production of nitrate in Chile is said to have been only 8,348 long tons.[1] In 1900 it was 1,473,091 long tons.[2] The combination of nitrate producers now estimates the production from April 1 of one year to March 31 of the following year. The production in this period from 1907 to 1908 was about 1,780,818 long tons, and from 1908 to 1909 it was about 1,808,986 long tons. The value of nitrate varies from year to year, but the price landed in New York or European ports in recent years has ranged between about $40 and $50 per long ton.

Nitrate reserves, taxes, etc.—Numerous estimates have at various times been made to determine the amount of crude nitrate existing in the nitrate regions. These estimates have differed very widely, some showing that the supply would be exhausted at the present rate of consumption in twenty-five or thirty years, others that it would last for three or four hundred years. The cause of this great diver-

[1] *Engineering and Mining Journal*, February 23, 1901, pp. 241, 242.

[2] *The Mineral Industry for 1901*, New York, 1901, p. 588.

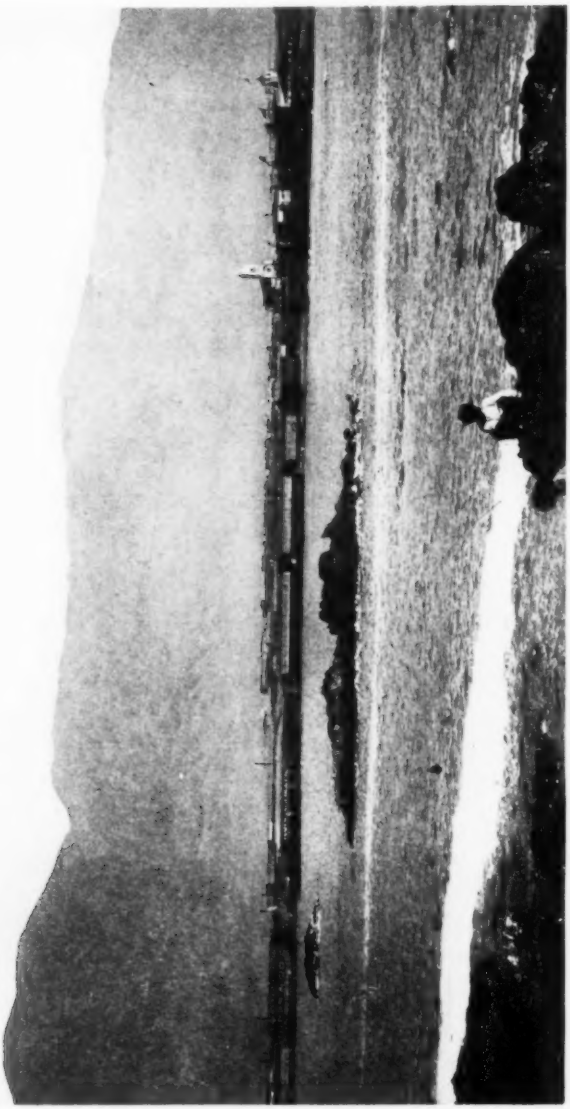

FIG. 7.—The city of Iquique, Chile.

gence is due to the premises on which the different estimates have been based. Many of those who predict a short life for the nitrate fields do not allow anything for future new discoveries of nitrates in northern Chile, whereas the probability of this is very great. The Chilean government owns all the nitrate deposits on the public domain and sells them only at auction. This policy has tended somewhat to retard individual effort at exploration, and hence vast regions in the Tamarugal Desert and the Desert of Atacama, which may contain nitrate, have not yet even been explored for it.

The nitrate that is being worked today, moreover, is very wastefully treated, and a large percentage of it is left in the refuse material accumulating around the oficinas; while the costra, or capping of the nitrate deposits proper, which is now only occasionally used as a source of nitrate, as it usually contains too low a percentage to satisfy the present operators, is collecting in vast quantities in the places where it has been mined and piled up to get at the purer material (caliche) below. Thus low-grade nitrate materials are gradually accumulating in immense amounts, and may be used in the future when more economical methods are introduced. These materials, together with the possible new discoveries of nitrate, render the future of the industry in Chile much more hopeful than some of the pessimistic prophets would lead us to believe; and for very many years to come Chile will doubtless be capable of supplying nitrate to the world.

As already stated the Chilean government owns all the nitrate lands on the public domain, and sells them at public auction from time to time, as occasion demands. The government also levies an export tax assessed in Chilean pesos. As the rate of exchange for the peso varies greatly from time to time, the amount of the tax as expressed in American money also varies greatly. A recent statement makes the tax equal to about 56 cents American money per quintel of 101.4126 pounds.[1] The combined revenues from the sales of nitrate lands and from taxes are so great that they pay a large part of the government expenses.

Uses of nitrate.—The nitrate of Chile is used for a number of

[1] These figures were kindly furnished the writer by Mr. Francisco J. Yánes, secretary of the International Bureau of American Republics, Washington, October, 1909.

different purposes, but by far the largest consumption is its use as an agricultural fertilizer, in supplying nitrogen to the soil. One of its earliest uses, and still a source of large consumption, is in the manufacture of niter, or potassium nitrate, for gunpowder. This is done by treating sodium nitrate with a salt of potassium. The nitrate of Chile is also used in the manufacture of nitric acid, and as nitric acid is an important factor in the manufacture of nitro-glycerine, dynamite, and other explosives, the consumption of Chile nitrate for such purposes is large. It is also used for many other chemical purposes on a smaller scale.

The value of sodium nitrate as a source of nitrogen in fertilizers has been known for a long time, but it has been only in comparatively recent years that it has been used on a very large scale. Formerly the nitrogen in fertilizers was supplied mostly from guano, fish scrap, leather scrap, and various other organic materials. The consumption of sodium nitrate in fertilizers now exceeds by many times its use for other purposes, and is rapidly increasing. The exhausted soils of Europe and of some parts of the United States, as well as of other countries, require year by year more fertilizing materials to make up for what is taken away by excessive cultivation, and some available compound containing nitrogen is one of the most important of such materials. Sometimes nitrate is used alone in cases where a nitrogenous compound is all that is needed, but more commonly it is used in admixture with phosphates, potassium salts, and other materials usually needed by depleted soils.

NITRATE DEPOSITS ELSEWHERE THAN CHILE

In parts of the world other than Chile, deposits of nitrates, especially potassium nitrate, and in smaller amounts calcium nitrate, have been found in many places, but nowhere in quantities in any way comparable with the sodium nitrate deposits of Chile, which today supply most of the world's demand. In old times, however, before this source became of commercial importance, potassium nitrate was obtained in considerable quantities in India and other tropical countries, where it occurs, often in association with calcium nitrate, in the soil and the grounds surrounding dwellings. Nitrate was also obtained in many parts of the world in caves, where it is found in

association with bat guano. In some cases, where these caves are in limestone, the nitrate occurs in the form of calcium nitrate, which was probably produced by the oxidation of the nitrogenous materials of the bat guano and the subsequent action of these oxidized products on the limestone. As caves in limestone are very common, the occurrence of calcium nitrate is frequently observed. In the old days nitrate was also made artificially from organic refuse in what were known as niter heaps. These produced mostly calcium nitrate, which was then converted to potassium nitrate. The nitrates in the soils of India and in the niter heaps were derived from nitrogenous animal matter, just as the cave nitrates were derived from guano, and the process in all these cases was made possible by the agency of certain bacteria already described in this paper (see p. 18).

In California, nitrate deposits occur in the arid region of the southeastern part of the state, in San Bernardino and Inyo counties, and elsewhere. The conditions there are not unlike those of northern Chile, the region consisting of high arid basins bordered by mountain ranges. The nitrate is mostly in the form of sodium nitrate, though some potassium nitrate occurs, and is associated with common salt (sodium chloride) and other saline materials, very much as in Chile. As yet these deposits have not become of much commercial value.

In recent years efforts have been made to obtain nitrogen from the air and to convert it to nitrates or other nitrogen compounds available for commercial purposes. The atmosphere contains nitrogen in the proportion of approximately 79 parts to the 100. This nitrogen, as has long been known, can be oxidized by electrical and other methods and converted to nitrates and other salts of nitrogen. Numerous methods for this operation have been devised, but their discussion is beyond the scope of the present paper, and the reader is referred to the readily accessible literature on the subject for further information.

GLACIATION ON THE NORTH SIDE OF THE WRANGELL MOUNTAINS, ALASKA[1]

STEPHEN R. CAPPS

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Since the pioneer trip of Lieutenant Henry T. Allen, in 1885, it has been known that a range of mountains lying north of the Chisana River, and later called Wrangell Mountains,[2] was heavily glaciated. The glacial phenomena of the Copper River basin and the south side of this range have been more or less fully discussed by various writers,[3] and some notes have been published[4] on the occurrence and position of glaciers and of Pleistocene deposits on the north side of this range, and in the White River Valley. During the summer of 1908, it was the writer's privilege to take a trip into the region north of the Wrangell Mountains with a party from the U. S. Geological Survey, in charge of Mr. Fred H. Moffit. The attempt is here made to summarize the glacial conditions of this region. In certain portions not personally visited, the unpublished maps and notes of F. C. Schrader, collected in 1902, have been drawn upon. The names of rivers, mountains, etc., referred to are taken from the topographic maps of the U. S. Geological Survey.[5]

The dominant topographic feature of the region under discussion is the Wrangell Mountains, extending from the Copper River basin in a southeastern direction to Russell Glacier and the headwaters of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] F. C. Schrader, *20th Ann. Rept.*, U. S. Geological Survey, Part VII, pp. 377, 378.

[3] F. C. Schrader and A. C. Spencer, *Geology and Mining Industry of a Portion of the Copper River District*, Alaska, 1901, p. 30; C. W. Hayes, *Nat. Geog. Mag.*, Vol. IV, 1892; Oscar Rohn, *21st Ann. Rept.*, U. S. Geological Survey, Part II, pp. 399–439; W. C. Mendenhall, "Geology of Central Copper River Region, Alaska," U. S. Geological Survey, *P. P. 41*, 1905.

[4] C. W. Hayes, *op. cit.*; A. H. Brooks, *A Reconnaissance from Pyramid Harbor to Eagle City, etc.*, U. S. Geological Survey, 1901.

[5] *Central Copper River Region, Alaska*, U. S. Geological Survey, 1902; *Headwater Regions of Copper, Nabesna, and Chisana Rivers, Alaska*, U. S. Geological Survey, 1902.

the Nizina River. In this range two peaks, Mount Sanford and Mount Blackburn, rise to heights of more than 16,000 feet. Mount Wrangell, a broad, dome-shaped mass, is 14,000 feet high, and many peaks of the range have elevations of from 12,000 to 13,000 feet. East of the Wrangell Mountains, and separated from them by Skolai Pass, is the northwest end of the St. Elias Range. The highest peak seen was Mount Natazhat, near the international boundary. This prominent mountain has a height of about 13,000 feet. North of the Wrangell Mountains and parallel with them, are the Nutzotin Mountains. The two ranges are separated on the west by the Copper River basin, and on the east by an area of low hills, but between the heads of the Copper and Chisana rivers, the two ranges approach one another without any sharp topographic break. The Nutzotin Mountains reach elevations, in their higher portions, of 8,000 to 10,000 feet. The large rivers are the Copper, which makes a great curve and flows south into the Gulf of Alaska, and the Nabesna, Chisana, and White rivers, all of which join the Yukon drainage.

Pleistocene Geology

The region covered by this report is bordered on the south by the high ranges of the Wrangell and St. Elias mountains. The name "Skolai Mountains" had been applied to a portion of this range, on either side of Skolai Pass. Structurally and physiographically, however, the Wrangell Mountains are continuous with the Skolai Mountains, which in turn are directly continuous with the St. Elias Range to the southeast. As the term Skolai Mountains does not apply to any natural division of this range, it is here omitted.

CENTERS OF GLACIATION

WRANGELL MOUNTAINS

A very important feature of the Wrangell Mountains is the great ice-cap which occupies the crest of the range, and which has its greatest development in the region around Mount Wrangell (Fig. 1). From the periphery of this great feeding-ground valley glaciers extend in all directions down the more important drainage lines. This report is concerned only with those glaciers of this group which extend to the north and northeast. In the Wrangell Mountains,

beyond the edge of the great ice-cap, there are numerous localities where the elevation is sufficient to start small glaciers. Small ice-tongues of this type occur between the Copper and Nabesna glaciers, and in the mountains east of the upper Nabesna River.

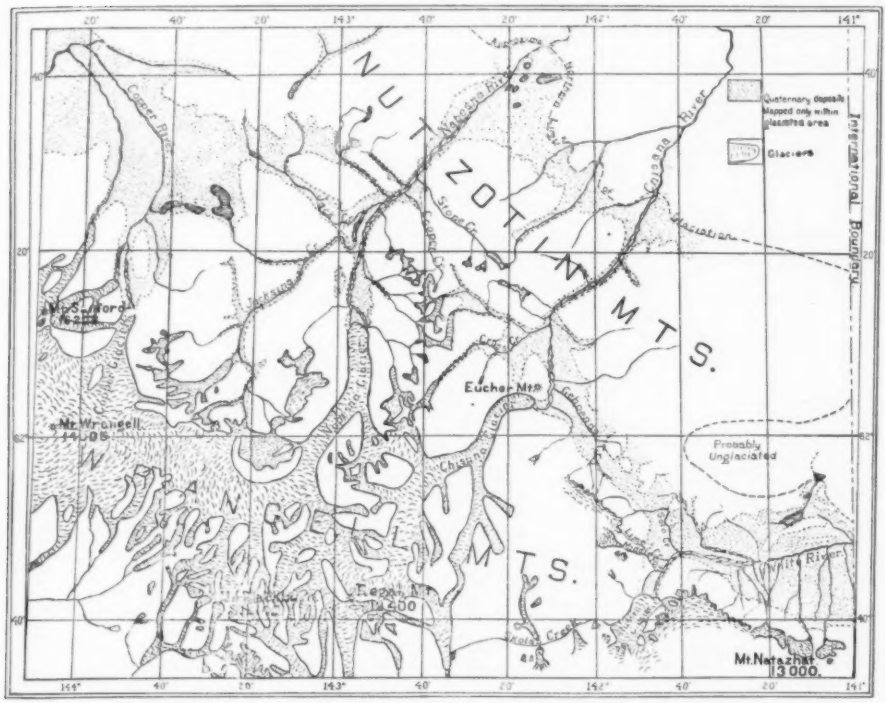

FIG. 1.—Map of a part of the Wrangell and Nutzotin mountains, Alaska. The existing glaciers are shown by the broken lines; the dotted areas show the distribution of the Quaternary deposits. The line of dashes indicates approximately the northern limit to which earlier glaciers reached. Compiled from published and unpublished maps of the U. S. Geological Survey.

ST. ELIAS MOUNTAINS

Second in importance in the region here discussed to the Mount Wrangell distributing center, is the ice-cap which occupies the St. Elias Mountains, south of the White River. Little is known of this ice-field, except along its northern border. As far as can be

seen from the White River Valley, all of the main range which lies west of the international boundary and south of the White River is capped with ice above an elevation of about 7,500 feet. As in the Wrangell Mountains, all of the important valleys which head back into the range are occupied by valley glaciers.

NUTZOTIN MOUNTAINS

A few small glaciers have survived in the more favorably situated valleys of the Nutzotin Mountains between the Chisana River and Suslota Pass. The largest of these is not more than three miles long.

INFLUENCE OF PRESENT GLACIERS UPON THEIR VALLEYS

Erosive effects.—The existing glaciers are now exerting a most important influence upon the shapes of their valleys. By the rasping of their beds with rock fragments held in the moving ice; by freezing to the bed rock and plucking out blocks of it; and by undermining the valley walls and causing the material above to fall down upon the glacier, the ice is enabled to remove great quantities of material from the valleys in which it is confined. The result of this erosion is to be seen in the characteristic shapes of the valleys in which it has been effective. Instead of the usual V shape of stream-cut valleys in rugged, youthful mountains, we find everywhere a broad U-shaped cross-section. The ice tends also to steepen the valley gradient toward the glacier-head, but to reduce it toward the foot of the glacier. In areas from which the ice has retreated, the bedrock often shows well-marked striations, or surfaces which have been smoothed or polished by the grinding. There is also a notable absence of sharp angular surfaces or protrusions of the bedrock, as all such projections have been worn away by the ice.

Effects on valleys below glaciers.—Glaciers also have an important influence upon the topography of the valleys below the ice-edge. All of the material which a glacier carries, either inclosed in the ice, or upon its surface, is ultimately carried toward the terminus and dropped as the ice melts away. It often accumulates as considerable moraine deposits, consisting of a heterogeneous mixture of angular or partly rounded rock fragments with finer clays. Often striae can be found upon the included bowlders.

Since the ice-borne materials are either deposited at the melting edge of a glacier, or beneath the body of the melting portion of the ice, there is always a great deal of running water present. Often streams of large volume flow out from beneath the glacier, but the volume of flow varies seasonably and daily as the temperature rises and falls. At times of rapid melting the streams carry large volumes of water, and are able to handle a great amount of the débris brought down by the ice. The material may be carried for long distances, or much of it may be dropped within a short distance from the glacier. The daily fluctuations in volume of the streams is an important factor in both the transportation and deposition of the débris.

Materials which have been deposited by streams differ notably in structure from those deposited directly by the ice. The water tends to assort the materials, and while the stratification may be very imperfect, the structure is readily distinguishable from that of glacial till.

Both the moraines and the stream-laid gravels form important topographic features in the valleys below the glaciers. The moraines are usually most prominent near the ice-edge, as they are readily cut away and destroyed by the streams. The outwash gravels are often of great extent, and the broad gravel bars with their anastamosing streams cover the valley floors of almost all the glacier-fed drainage lines.

EVIDENCES OF EARLIER AND MORE EXTENSIVE GLACIERS

We have seen that glaciers have an important influence upon the valleys which they occupy, both in determining the shape of the valleys, and in causing the deposition of moraines and gravels. These evidences are definite, and would remain even if the ice should melt and disappear. In the region under discussion there is abundant evidence of this sort, which shows that at no distant geological period the glaciers were of much greater size and extent than they are now. The valleys have been broadened and deepened, and show a marked U shape in cross-section far below the limits of the present ice. Furthermore, the rock surfaces are often striated, and there are unmistakable deposits of glacial till at many points from which the ice has long ago disappeared. In the Nabesna Valley, for example, the ice probably extended 40 or 50 miles to the northeast from the edge

of the present glacier, and spread out upon the plain at the north base of the Nutzotin Mountains. At this time, the glacier was about 100 miles long from its terminus to the top of Mount Wrangell, where it headed. Other glaciers of this region were proportionately greater.

An attempt has been made, based on somewhat incomplete data, to show the northern limits of the glaciers in this region at the time of their maximum extent (Fig. 1). The glaciated area includes all of the Wrangell, Nutzotin, and Skolai mountains. It is probable that at no time were the Nutzotin Mountains entirely ice-covered, but only the highest peaks and ridges projected above the glacier, and the total area of these projecting points was very small.

COPPER RIVER VALLEY

The Copper River heads in a glacier which receives the ice from the north slope of Mount Wrangell and from a part of the east slope of Mount Sanford. Although seen only at a distance by the writer, its general characteristics can be learned from the topographic map. In length this glacier is much inferior to those in the valleys of the Nabesna and Chisana rivers, to the east. It is about 20 miles long from the top of Mount Wrangell to the terminus, and has an area of approximately 140 square miles.

Small glaciers in the Copper drainage.—East of the main ice-body there are three small glaciers which lie high up the rock-wall and fail to send their ice-tongues down to join the main lobe. On the west, West Glacier moves from Mount Sanford down to the main valley, which it reaches three miles below the end of the Copper Glacier. Drop Glacier, still farther to the northwest, is the last ice-tongue of importance within the boundaries of the region under discussion.

Glacio-fluvial deposits.—Below the edge of the mountains the great Copper River basin extends to the north and west. The basin is covered with extensive gravel deposits which contain a great variety of beds ranging from coarse gravels and unassorted glacial till to finely assorted clays and silts. The extension of these beds to the west and south has been discussed by Mendenhall.[1] Toward

[1] *Op. cit.*, pp. 62–72.

their upper end they appear as a broad plain into which the rivers have cut considerable valleys.

Extent of earlier glaciers.—In the Copper River Valley, as in all the valleys of these mountains, the ice has formerly been much more extensive than at present. The mountain just below the glacier was once surrounded, and perhaps entirely covered by the ice. Mendenhall advanced the opinion that the entire Copper River basin was probably at one time occupied by ice.

NABESNA VALLEY

Nabesna Glacier.—The Nabesna Glacier is the great body of ice which occupies the head of the valley of the same name. It receives the ice from a great portion of the north slopes of the Wrangell Mountains, its feeding-ground extending from Mount Wrangell in an east-southeast direction to Mount Regal, a distance of 43 miles. The outlines of the glacier form a complicated dendritic pattern, as about 40 cirques contribute their ice to it. At a point 20 miles northeast of Mount Blackburn the ice is confined within a single valley and forms a lobe a little more than two miles wide. Below this point the glacier is of nearly uniform width, and receives but a single important tributary. It moves from this point northeast and then north to its terminus, a distance of 20 miles. The total length of the glacier, from Mount Wrangell to its lower end is about 55 miles, and its area approximately 400 square miles.

As viewed from the mountain-side, below Nikonda Creek (Fig. 2), the main lobe of the glacier shows a fairly smooth surface and a uniform slope as far as the eye can see. There are no cascades or steep pitches on the surface, although the great branch which comes in from the direction of Mount Regal descends steeply into the main valley. The surface slope of the main lobe is about 50 feet per mile.

Moraines.—A prominent medial moraine follows the center of the glacier for many miles above its lower end. It is flanked closely on either side for a part of its length by narrower parallel moraines. The débris showing on the surface becomes more prominent to the northward, and near the terminus the band-like ridges become so frequent that at its north edge the ice is entirely covered by rock débris, and grades imperceptibly into the terminal moraine.

About one mile above Nikonda Creek a rock island or nunatak stands up through the ice. Its surface is covered with loose material, but is bare of vegetation.

The terminal moraine of this glacier covers the valley floor for about two miles below the ice-edge, except for narrow valleys on the east and west through which the waters of the melting glacier escape to the north. The moraine surface is of very irregular topography,

FIG. 2.—The Nabesna Glacier.

and consists of a succession of hummocks and kettles, many of which contain lakelets. No well-established drainage lines were observed.

The extent of the terminal moraine shows that the glacier is at present retreating. It has been deposited so recently that over most of it no vegetation has as yet obtained a foothold. Along the northern edge there is a low growth of bushes, but no trees of size.

Small glaciers in the Nabesna drainage.—There are a number of small glaciers to be found at the heads of tributaries of the Nabesna, which themselves do not connect with the main glacier, or extend

down to the trunk valley. Of those on the east five drain into Nikonda Creek, nine into Bond Creek, three into Camp Creek (Fig. 3), at least one into Cooper Creek, and three into Stone Creek. From the west, about ten glaciers drain into Jacksina Creek and one into Platinum Creek. Almost all these are cliff glaciers of small area, and are but the remnants of larger bodies of ice which formerly occupied the valleys.

Glacio-fluvial deposits.—The Nabesna Valley, from the terminal moraines to the north base of the Nutzotin Mountains, is floored by

FIG. 3.—Glacier at the head of Notch Creek, and small cliff glaciers on the walls above.

gravel beds. The bars are from one to three miles wide, and the river anastamoses over much of this flat in periods of high water. Although the current is swift, the stream is heavily loaded, and the flat is constantly being built up by the outwash from the glacier.

The stream fluctuates daily in volume in the summer season. It is a well-recognized fact by travelers in this region that streams which are not fordable in the afternoons of warm days can be easily crossed on cold days, or in the early morning before the melting ice has swelled the current. In times of high water the main channels may locally deepen their beds. Large bowlders are moved, and can often be heard bumping along the bottoms of the streams. At the same time, the heavily burdened waters may be depositing rapidly in the shallower and more sluggish channels. In the night time,

and on cold days, deposition is general throughout all the stream-courses.

The character of the valley gravels changes notably as one proceeds down stream. Near the glacier the gravels are generally coarse. Farther down they become progressively finer and finer, and bars of small gravel and sand take the place of the cobbles so abundant above.

All of the larger tributaries of the Nabesna River, including Nikonda, Bond, Cooper, and Stone creeks from the east, and Monte Cristo, Jacksina, Jack, and Platinum creeks from the west, have gravel bars similar in origin to those in the main Nabesna Valley, but smaller in size.

Terraces.—The conditions for the deposition of the gravel beds in the Nabesna Valley have not been uniform since the withdrawal of the greater glacier, and it is not to be expected that they would have been. The retreat of the ice probably consisted of many withdrawals interrupted by halts, or even by slight readvances, and from time to time the quantity of water, as well as the abundance and variety of the materials to be transported would have varied. At times of ice-advance the streams were supplied with an excessive amount of detritus, and would therefore have built up their beds with great rapidity. Later, with a comparative scarceness of gravels to be carried, the streams would have been able to entrench themselves in the gravel bars already formed. That some such conditions actually did exist is shown by the terraces of stream-laid gravels which are now to be seen at various places along the Nabesna Valley. These terraces have their best development between Bond Creek and California Creek. At their upstream end they reach an elevation of about 200 feet above the river, but slope gradually downward to the north, and near Bond Creek merge with the gravel bars which the river is now building.

Just south of California Creek, the plain-like surface of the terraces is broken by a number of low, irregular hillocks, composed of glacial till. These indicate that the terrace gravels were here laid down around and on top of a terminal moraine during the retreat of the glacier. The stream has now cut its channel 200 feet into these gravel beds.

For some distance above Camp Creek, and between Copper and Stone creeks, there are gravel terraces which stand 30 to 50 feet above the stream.

Extent of earlier glaciers.—As shown in Fig. 1, the Nabesna Glacier was formerly of much greater size than it is at present. The glaciers from the Wrangell Mountains, moving northward, were unable to override the opposing Nutzotin Mountains, but sent their ice across this range through the two great troughs through which the Nabesna and Chisana rivers now flow. In the Nabesna Valley the ice extended to the north base of the Nutzotin Mountains, and there spread out into a broad, spatulate lobe. The outlines of this lobe have not been traced, but there is reason to believe that its northern edge was 40 or 50 miles below the existing ice-edge. The ice filled the valley to a depth of 2,000 to 3,000 feet, and its erosive power was enormous. It truncated the lower ends of the rock spurs on either side of the valley and developed the broad U-shaped trough through which the river now flows. There is a notable absence of craggy outcrops and of ridge-like spurs along the valley-sides.

At the time of the maximum ice-advance each tributary valley in the Wrangell and Nutzotin mountains sent down a glacier to join the main lobe so that only the highest peaks and crests of the mountains projected above the ice. With a change in climatic conditions came a gradual contraction of the glaciated area. The ice in the large trunk valley slowly melted back and left separate the small glaciers which occupied the side gulches. These in turn retreated toward their heads, and although many of them have now disappeared entirely, their former presence is shown by the U shape of the stream-troughs, and by the moraines which the ice left.

CHISANA VALLEY

Chisana Glacier.—The Chisana Glacier, locally called the Shushana, lies on the northeast slope of the Wrangell Mountains, between the Nabesna and White valleys. Its heads reach westward to the Nabesna divide, and in many of the cirques the ice is continuous across the divide with the easternmost heads of the Nabesna. To the south the ice is continuous over the divide with the Rohn and Nizina glaciers on the south slope of the mountains (Fig. 4). There

are but 14 tributary cirques, as compared with 40 to the Nabesna Glacier, and the total area of ice is about 135 square miles. Its length, from the terminus to the Chisana-Rohn divide, is 30 miles.

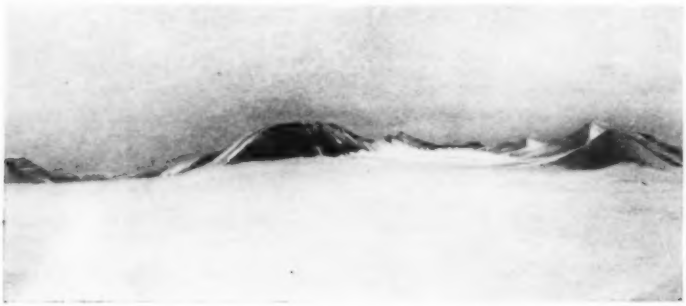

FIG. 4.—The summit of the Chisana-Rohn divide. Photograph by Rohn, 1899.

A fine view of the glacier can be obtained from Euchre Mountain, at its lower end. The glacier, which for about twelve miles above Euchre Mountain consists of a single lobe, swings in a broad curve from a north to an eastern direction. Its surface, so far as could be

FIG. 5.—Lower end of the Chisana Glacier. Photograph by Rohn, 1899.

seen, was free from sharp breaks in gradient and from prominent crevasses (Fig. 5).

Moraines.—A prominent medial moraine belt, lying somewhat west of the center of the glacier, appears on the surface far above the great bend of the ice. At the bend it has a curious zig-zag shape,

and extends to the ice-edge above Euchre Mountain. It is the only continuous belt of moraine to be seen from this mountain.

There is an almost complete absence of distinct terminal moraine deposits, and it is concluded that the glacier is retreating. If this is the case, however, the ice-movement must be very slow, for a comparison of the photographs taken by Rohn[1] in 1899 with those taken by the writer nine years later show surprisingly little change in the aspect of the glacier. The moraines appear the same, and there are only slight changes in the courses of the streams below the ice-edge. At one place a slight recession has taken place in the edge of the glacier.

Small glaciers in the Chisana drainage basin.—There are a number of small glaciers which drain into the Chisana Valley. On the east several little ice-lobes project down from the ice-field which caps the mountains southeast of Euchre Mountain. These form the heads of Bow and Gehoenda creeks. On the west, four small glaciers drain into Cross Creek, two from the Wrangell Mountains (Fig. 1), and five from the Nutzotin Mountains into Notch Creek. Mount Allen supports two little ice-tongues which drain into the Chisana below the mouth of Cross Creek.

Glacio-fluvial deposits.—The valley below Euchre Mountain contains broad gravel bars built up by the streams from the glacier. The stream-laid deposits differ notably, however, from those found immediately below the Nabesna Glacier. Here coarse gravel is the exception, and as far north as the mouths of Cross (Copper) and Chavolda creeks, the bars are largely composed of fine gravels and sands. The valley is wide and the stream breaks up into a multitude of channels. On the afternoons of warm days, these channels were observed to overflow and join until much of the wide flat was covered by a thin sheet of water.

Below the mouth of Cross Creek, the gravels become much coarser, as this creek discharges coarse gravels. The valley through the Nutzotin Mountains is a narrow U-shaped gorge, and the waters flow in a few large channels. Through the gorge there is shown the usual succession of coarse gravels above, becoming progressively finer down stream.

[1] Oscar Rohn, *21st Ann. Rept.*, U. S. Geological Survey, Part II, Pl. LV.

All of the larger tributaries of the Chisana River, including Bow, Gehoenda, Chathenda, and Chavolda creeks from the east and Cross Creek from the west, have valleys floored with gravels, and most of these streams have developed fans where their gravel bars coalesce with those of the main valley.

Terraces.—Conspicuous terrace deposits occur at several points along the valleys of the Chisana and its tributaries. East of Euchre Mountain, and including the lower portions of Bow, Gehoenda, and Chathenda creek valleys, there is a broad area of gravel deposits into which these streams have entrenched themselves. The area now covered by these gravels was formerly occupied by the Chisana Glacier. As the glacier decreased in size the ice-edge gradually shrank back toward the west and exposed this region, while it was still of sufficient thickness in the main Chisana Valley to form an obstruction to the streams from the east. Under these conditions the creeks rapidly built up their valleys with alluvial material. It is even possible that temporary lakes were formed behind the ice-dam. An exposure along Gehoenda Creek for several miles above its mouth shows fine, stratified gravels and silts, interbedded with coarser materials. The rather perfect stratification of the finer materials suggests a lacustrine origin for these beds.

On Notch Creek there are terrace gravels on both sides of the stream. They occur intermittently from the base of the mountains near the head of the creek to its mouth, and in places the stream-cut bluff shows a section of 150 feet of the coarse, rudely stratified gravels with interbedded lenses of sand. They are evidently stream-laid and may have been deposited synchronously with the terraces in the Nabesna Valley described above.

About ten miles below the mouth of Chavolda Creek, on the northwest side of the Chisana River, there is a good exposure of terrace gravels. In the bank about 60 feet high the lower 40 feet are exposed. The section (Fig. 6) shows 15 feet of coarse gravel at the base, with occasional bowlders 18 inches in diameter. Above this is 25 feet of fine, well-stratified gravel with pebbles five inches or less in diameter. The terraces were probably built contemporaneously with those in Notch Creek.

Extent of earlier glaciers.—As is the case in other valleys of this

region, the Chisana trough has very evidently been occupied at no very remote period by a glacier of much greater extent than the present one. It pushed from the Wrangell Mountains northeast through the Nutzotin Mountains to their north base, and was very deep throughout the valley. On Euchre Mountain there are moraines and erratic bowlders up to the 6,600-foot level, or 2,500 feet above the terminus of the present glacier, and in the low col west of this mountain there must have been at least 1,200 feet of ice which moved northward. Euchre Mountain at that time was an island standing about 1,000 feet above the surface of the surrounding glacier. East and northeast of Euchre Mountain the ice was not confined by steep valley-walls, and doubtless spread out into a wide lobe at this place. Below Chavolda and Cross creeks it was again compressed to a narrow tongue in the canyon-like valley through the Nutzotin Mountains, and probably again deployed on the plain to the north of this range.

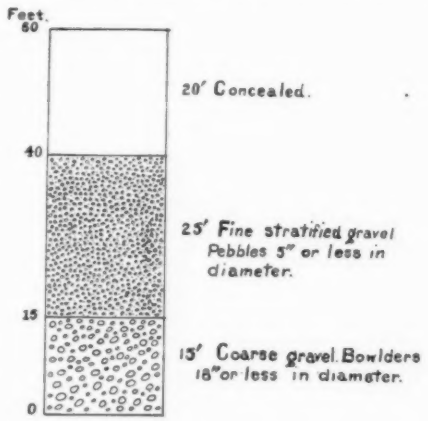

FIG. 6.—Section of gravel terrace on the Chisana River, 10 miles below the mouth of Chavolda Creek.

At the climax of this glacial period, each tributary valley of the Chisana, both in the Wrangell and Nutzotin mountains, was occupied by a glacier which joined the body of ice in the main valley. It is probable that the whole mountainous area had much the same appearance at that time as that shown by the higher parts of the Wrangell Mountains now (see Fig. 4).

Since the retreat of the ice to its present position, the greater number of tributary valleys have been deglaciated; and only the higher and more favorably situated summits have perennial ice upon their flanks.

In the canyon of the Chisana, between the mouth of Chavolda Creek and the north base of the mountains, the rock valley walls show in many places one or more smooth, rounded benches, due to glacial erosion. The benches are inconspicuous when near at hand, but are plainly discernible from a distance. They can rarely be followed for more than a mile or so, and it was impossible, in the short time available, to correlate the benches in different parts of the canyon.

WHITE VALLEY

Russell Glacier.—The head of the White River is occupied by a body of ice which was first crossed in 1891, by C. W. Hayes, and was named Russell Glacier[1] by him. The pass over this glacier he named Skolai Pass, and from this fact the name Skolai Glacier is commonly used in the region. The feeding-ground from which this ice-field moved is located in the high mountains east and southeast of Skolai Pass, and as these mountains have never been accurately mapped, no data is available for determining the area and length of the glacier.

As stated above, all the valleys which supply ice to the main glacier head to the east and south. The northernmost of these, at the head of Moraine Creek, joins the main lobe near its terminus. The tributary valley divides, a short distance above its mouth, into two cirques which head in the snow-capped mountains to the east. South of Moraine Creek there are four important tributary glaciers, all of which have their sources in the high, snow-capped, unexplored mountains (Fig. 7).

The main lobe of ice in the head of the White Valley is between 6 and 7 miles long, and about $2\frac{1}{2}$ miles wide, and most of the ice moves in a northeast direction. A small crescentic lobe, however, moves westward into the head of Skolai Creek.

The surface of Russell Glacier is for the most part much crevassed and difficult to cross. The lower two or three miles of ice are moraine-covered, and have been melted into rugged surface shapes in which the ice can be seen only where the slopes are too steep to hold the moraine material. Numerous lakelets were seen to occupy basins in the ice (Fig. 8). Above the moraine-covered portion of the glacier

[1] *Nat. Geog. Mag.*, Vol. IV, 1892, p. 152.

there is a belt, near the west edge, in which the surface is free from

FIG. 7.—View showing surface character of the upper portion of Russell Glacier.

débris and level enough to make travel easy. Here there are few crevasses for a distance of perhaps three miles. As the lobe which

FIG. 8.—A lake in the moraine-covered ice of Russell Glacier.

moves into the valley of Skolai Creek is approached, the ice-surface again becomes broken and irregular, with rugged, moraine-covered

areas and great systems of cracks at right angles to the Skolai Creek Valley (Fig. 9). There is little terminal moraine bordering this lobe, and Skolai Creek has a flat bar composed for the most part of silty quick-sands.

Moraines.—A number of belts of medial moraine lie upon the surface of this glacier. The most important one extends continuously down the center of the main ice-lobe. Other less conspicuous lines occur below the junction-points of the various heads.

The terminal moraine forms a great lobe at the head of White River. It was impossible to determine the line where the glacier ice ends and the terminal moraine begins, as the two blend imperceptibly. A considerable area of the ice is moraine-covered, and there is doubtless much ice inclosed in the moraine deposits. The moraine is a confused jumble of fine material and rock fragments of all sizes and shapes. Drainage lines have been developed only along its edges.

Russell Glacier seems to be retreating. The terminal moraine is new and barren of vegetation, and the ice above it is much decayed. The comparatively recent age of the moraine is also attested by a large admixture of the volcanic ash which is of widespread occurrence in this region, and which lies as a white covering on the lower spurs of the ridges north of Mount Natazhat.

Small glaciers in the White River basin.—In some of the tributary valleys to the west and south of the White River there are small glaciers, the remnants of ice-tongues which formerly reached down to the main valley. In Middle Fork and Lime creeks to the west, the valley-heads contain glaciers, and smaller ice-fields lie on favorable places along their walls. Wiley Creek, to the east of the great terminal moraine, has an ice-field at its head. All the small streams which join the White River between the great bend and Holmes Creek, head in lobes of the ice-cap which covers the range. Holmes Creek has a deep valley which extends for some distance back into the mountains, and a glacier occupies this canyon to its mouth. Mount Natazhat and the great ridge extending west from it, form a series of magnificent cirques, with ice-tongues which extend to the foot of the mountains (Fig. 10).

Glacio-fluvial deposits.—The gravel deposits now being laid down

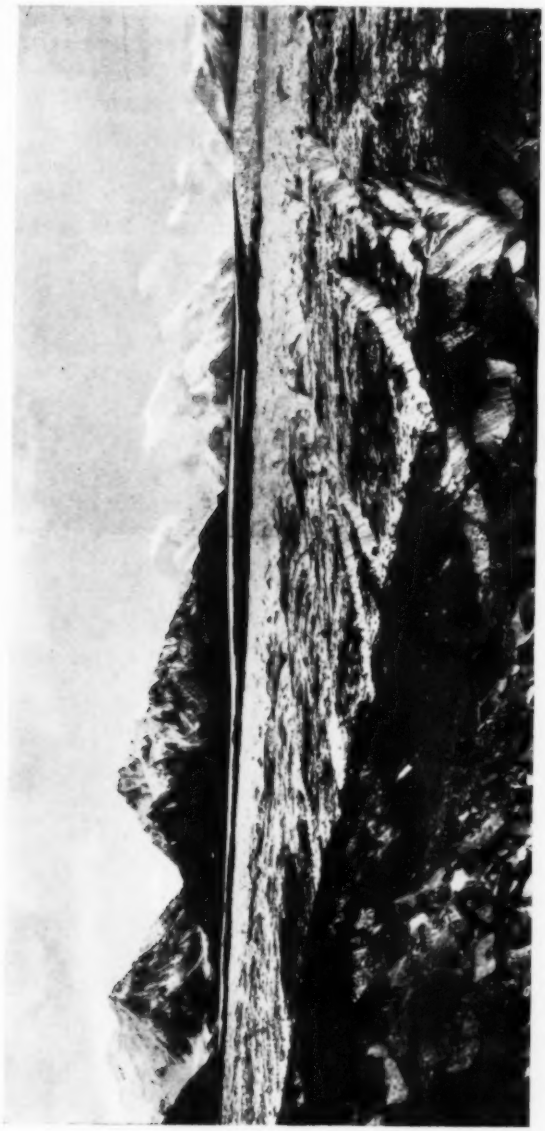

FIG. 9.—View toward the head of Russell Glacier. A medial moraine appears in the immediate foreground, and another in the middle distance.

in that part of the White River Valley which lies west of the international boundary, are very extensive. The area of deposition varies in width from about two miles, just below the glacier, to about nine miles, south of Mount Natazhat. For the first ten miles below the glacier the valley is flat from side to side and is for the most part bare of vegetation. East of Ping Pong Mountain, the White River itself occupies only a narrow valley close to the base of a rock ridge. The remainder of the broad valley to the south slopes upward toward the mountains, and consists of a compound alluvial fan built up by

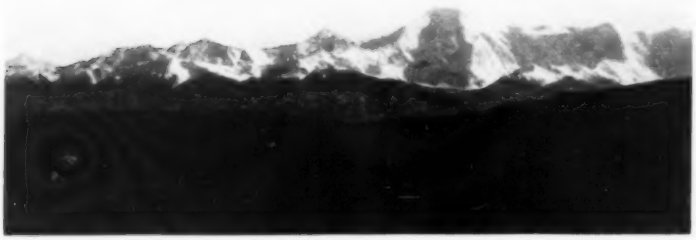

FIG. 10.—Mount Natazhat, and the great cirques on its flanks. Each of these cirques is occupied by a glacier. Photograph by F. H. Moffit.

the tributaries from the south. This fan is heavily timbered except for narrow belts along the streams. The present course of the White River has been determined by this alluvial fan which has crowded the river north against the base of Ping Pong Mountain.

Fig. 11 is a diagrammatic cross-section of the White Valley, five miles west of the boundary. If we can assume that the wide valley north of Mount Natazhat was eroded by the great glacier to an average depth equal to the present level of the White River (*a*), then the valley filling of alluvial gravel must be more than 400 feet thick in the center of the old valley (*b*). Since the White River was nowhere observed to have cut its valley down to bedrock, and since the bedrock level at (*b*) is probably lower than at (*a*), the thickness of the gravels in the deepest portions of the old valley may greatly exceed 400 feet.

Aside from the fan-building streams from the south, the valleys of North Fork, Lime Creek, Middle Fork, and Wiley Creek all have gravel bars extending upstream for some distance above their junctions with the White River gravels.

Terraces.—In this valley remnants of high terraces were noted only on the north side of the river. For about two miles below the mouth of the Lime Creek Canyon, there is a bench of coarse gravels from 30 to 50 feet high. Farther east, along the south base of the Ping Pong Mountain ridge, the river bluff shows a 50-foot cut. Of this section (Fig. 12), the lower 35 feet are composed of coarse, rudely stratified

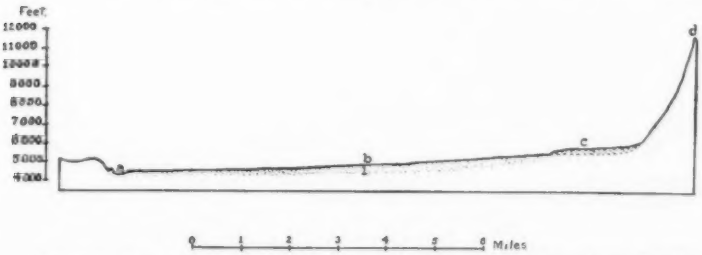

FIG. 11.—A north-south section across the White River Valley, about 5½ miles west of the international boundary. *a*, White River; *b*, alluvial fan; *c*, small glacier; *d*, peak two miles west of Mount Natazhat.

gravels. Above this are 15 feet of blue glacial till. Locally the gravel beds immediately below the till are much distorted and crumpled, showing that after the gravels were deposited, the glacier advanced over them, disturbing their bedding and depositing a sheet of till. There may be gravels of the same age south of the White River, but the present tributaries from the mountains to the south are so actively engaged in building alluvial fans that any remnants of higher terrace gravels which might have existed on that side of the river have been cut away, or covered up by more recent deposits.

Extent of earlier glacier.—At the time of the great ice-advance, a glacier, of which Russell Glacier is the surviving remnant, moved eastward along the White Valley and extended well across the international boundary. At the boundary it had a width of more than 10 miles, and its surface stood more than 1,600 feet above the present level of the White River at this place, for there are evidences of glacia-

tion at the top of a 1,600-foot hill just east of the boundary. The glacier also covered the ridge of which Ping Pong Mountain is the west end. Unlike the ice-fields which occupied the Nabesna and Chisana valleys, this one was not fed by tributaries from both sides of its valley, but only from the valleys of the high mountains to the south and west.

The severity of the glacial erosion upon the valley walls is well shown by the abrupt triangular faces of the spurs opposite the mouths of North Fork and Solo creeks.

Solo Creek gravels.—North and west of Solo Creek there is a broad, flat area covered with outwash gravels, which were laid down under much the same conditions as were those east of the Chisana Glacier. Here the receding ice in the White River Valley left bare a broad area which normally drained into the White River. The drainage was here impeded by the valley glacier, which must have occupied the valley long after the higher area to the north was deglaciated. During this period of obstructed drainage extensive gravel beds were laid down, which abutted against the ice to the south, and spread northward and filled the old drainage channels. The filling went on to such an extent that some of the streams found a lower outlet to the northeast, and still flow in that direction. Solo Creek has now cut a considerable gorge through the gravels and into the underlying rock, and is gradually recapturing for the head of the White River the drainage lost during early glacial times.

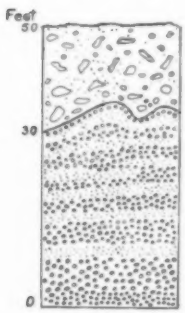

FIG. 12.—Section of terrace on White River, showing glacial till above, and gravels below. The upper portion of the gravel beds has been distorted by the over-riding ice.

Ptarmigan Lake gravels.—Between North Fork and Ping Pong Mountain, a broad flat has a gravel covering due to the same causes as those which brought about the deposition of the Solo Creek gravels.

Ptarmigan Lake would normally drain into the White River to the south, but its waters found an outlet by way of Beaver Creek at the time the glacial ice in the White River Valley formed a barrier to drainage in that direction. The development of its gulch by Cache Creek may some day result in the recapture of this drainage, as the gulch is now being rapidly deepened headward.

GLACIERS IN SKOLAI CREEK DRAINAGE

Skolai Creek is the stream which flows eastward from a lobe of Russell Glacier, and after traversing a narrow, deep valley for about 17 miles, is impounded to form a lake at the edge of the Nizina

FIG. 13.—Terminus of Frederika Glacier. This glacier terminated, in 1891, in an ice-cliff 250 feet high. Photograph by F. H. Moffit.

Glacier, and has its outlet beneath this ice-dam. From the north a single ice-lobe, Frederika Glacier, drains into Skolai Creek. C. W. Hayes, who saw this glacier in 1891, says of it,

> The glacier terminates in a nearly vertical ice cliff stretching across the lateral valley a mile in length, and about 250 feet high. Its surface is free from moraine, but is extremely rough and broken, wholly unlike the surface of stagnant ice at the end of a retreating glacier.[1]

He also mentions this glacier as being the only one seen that summer which appeared to be actively advancing. As seen by the writer, the

[1] *Nat. Geog. Mag.*, Vol. IV, 1892, p. 133.

glacier now terminates about one mile north of Skolai Creek. Its surface is remarkably smooth and slopes down evenly to a thin edge in front (Fig. 13). It was found to be easier to take a pack train across this low ice-tongue than to ford the torrential stream below.

From the south, a number of glaciers drain into this valley. About three miles below Russell Glacier a moraine-covered ice-lobe pushes down to the valley and dams the stream so that a considerable lake is

FIG. 14.—An advancing glacier in Skolai Creek Valley, opposite Frederika Glacier.

formed. Opposite the mouth of Frederika Creek, a beautiful cascade glacier tumbles out from between castellated peaks and pushes northward to Skolai Creek (Fig. 14). It is evidently an advancing glacier now, and was the only one seen during the season which seemed to be advancing. The writer is unable to account for the singular change in conditions which has caused Frederika Glacier, which 17 years ago was advancing, to retreat, and at the same time has brought about the advance of a glacier just to the south, which in 1891 was retreating.

Below Frederika Creek there are several small cliff glaciers on the south valley-wall. At their heads the rock rises almost perpendicularly for a thousand feet or more. On a warm afternoon, great blocks of ice from above could be seen to break off and fall down this cliff with a great noise. The ice was broken to fine fragments before it reached a lodgment below.

THE CALCULATION OF THE NORM IN IGNEOUS ROCKS

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In presenting to successive classes of students in petrography the method of calculating the norm for igneous rocks under the quantitative classification of Cross, Iddings, Pirsson, and Washington, the writer has found such a selection of calculated analyses as is here given, accompanied by discussion, of great service. For practice in calculation the collection of analyses with their norms by Dr. H. S. Washington given in *Professional Papers 14 and 28* of the U. S. Geological Survey is invaluable. Of the calculated analyses which follow, all but two are taken from *Professional Paper 14*. By using the tables given at the end of the *Quantitative Classification of Igneous Rocks*[1] the arithmetical work in calculating the norms is very greatly lessened. The first set of tables, prepared by Professor J. F. Kemp and originally published in the *School of Mines Quarterly*,[2] gives the molecular proportions for the percentage figures of the several oxides recorded in rock analyses. The second set of tables in the *Quantitative Classification of Igneous Rocks* gives the percentage weights for various proportions of molecules of the standard rock-making minerals. The molecular proportions may be calculated by dividing the percentage figures for each oxide by the molecular weight of the oxide. Thus for 65.70 per cent. silica the molecular proportion is 1.095, the molecular weight of SiO_2 being 60. The molecular proportion for 15.40 per cent. soda is .248, the molecular weight of Na_2O being 62. As a preliminary step in the calculation of an analysis the molecular proportions for each oxide must be looked up in the tables. Small amounts of MnO (.001 to .005), and NiO are to be used as FeO;

[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago: The University of Chicago Press, 1903), pp. 237–59.

[2] J. F. Kemp, "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, XXVII, 75–88.

and in the same manner small amounts of BaO and SrO are to be added in with the CaO. If Cr_2O_3 does not amount to .002 it is to be added in with Fe_2O_3. For the calculation of a rock analysis we then start with the molecular proportions of the ten oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, K_2O, TiO_2, and P_2O_5, which are contained in nearly every rock, and we may also have present ZrO_2, SO_3, Cl, F, and CO_2, besides H_2O; and, in smaller amounts, MnO and NiO to be summed in with FeO; BaO and SrO, to be added to CaO; and Cr_2O_3 which is to be counted as Fe_2O_3. ZrO_2, Cr_2O_3 in amount more than .002, TiO_2, P_2O_5, SO_3, Cl, CO_2, and F, when they are present, are first calculated as minor inflexible molecules. Their calculation as zircon, chromite, ilmenite, apatite, noselite, sodalite, calcite, and fluorite presents no difficulty, for the method of procedure is always the same. The eight oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, and K_2O are of much greater importance in the calculation of the norm, for any one of these oxides in a given analysis is disposed of with regard to the relative quantities of all the others. The difficulty in presenting to the student the method of procedure in its entirety lies in the fact that a rather long series of considerations is to be put before him at the very outset. The aim of the writer in the present paper is to develop little by little with the aid of examples and discussions the condensed, precise statement of the authors of the *Quantitative Classification of Igneous Rocks*, pp. 188–96.

The simplest cases are those in which SiO_2 and Al_2O_3 are present in relatively large amounts so that they meet all claims upon them and are not exhausted. Al_2O_3 remaining over is corundum, and SiO_2 remaining over after all the allotments is quartz. With SiO_2 present in abundance Al_2O_3 may meet all the claims of K_2O, Na_2O, and CaO upon it; or it may satisfy K_2O, Na_2O, and part of the CaO. Again it may satisfy only K_2O and part of the Na_2O; or, rarely, only part of the K_2O. So the treatment varies.

The norm minerals of the two groups, which figure in the calculation, with the abbreviations for their names, and their formulas, are as follows. The table is intended to set forth the relative importance of their several rôles in the norm.

I. SALIC GROUP

Dominantly Siliceous and Aluminous

A.	Quartz	SiO_2	Q.
	Corundum	Al_2O_3	C.
	Orthoclase	$K_2O.Al_2O_3.6SiO_2$	or.
	Albite	$Na_2O.Al_2O_3.6SiO_2$	ab.
	Anorthite	$CaO.Al_2O_3.2SiO_2$	an.
	Leucite	$K_2O.Al_2O_3.4SiO_2$	lc.
	Nephelite	$Na_2O.Al_2O_3.2SiO_2$	ne.
	Kaliophilite	$K_2O.Al_2O_3.2SiO_2$	kp.
B.	Minor inflexible molecules		
	Sodalite	$3(Na_2O.Al_2O_3.2SiO_2).2NaCl$	so.
	Noselite	$2(Na_2O.Al_2O_3.2SiO_2).\ Na_2SO_4$	no.
	Zircon	$ZrO_2.SiO_2$	Z.

Of the salic minerals kaliophilite is very rare, while sodalite, noselite, and zircon are much less rare but still unusual. (See note at end of paper on the substitution of halite, NaCl [Hl], and thenardite [Th], Na_2SO_4, for sodalite and noselite, respectively, among the salic minerals.)

II. FEMIC GROUP

A.	Diopside	$CaO.(MgFe)O.2SiO_2$	di.
	Hypersthene	$(MgFe)O.SiO_2$	hy.
	Olivine	$2(MgFe)O.SiO_2$	ol.
	Acmite	$Na_2O.Fe_2O_3.4SiO_2$	ac.
	Sodium metasilicate	$Na_2O.SiO_2$	ns.
	Potassium metasilicate	$K_2O.SiO_2$	ks.
	Wollastonite	$CaO.SiO_2$	wo.
	Ackermanite	$4CaO.3SiO_2$	am.
B.	Minor inflexible molecules		
	Magnetite	$Fe_2O_3.FeO$	mt.
	Ilmenite	$FeO.TiO_2$	il.
	Chromite	$FeO.Cr_2O_3$	cm.
	Hematite	Fe_2O_3	hm.
	Titanite	$CaO.TiO_2.SiO_2$	tn.
	Perofskite	$CaO.TiO_2$	pf.
	Rutile	TiO_2	ru.
	Apatite	$3CaO.P_2O_5.\ \frac{CaCl_2}{3}$ or $3CaO.P_2O_5.\ \frac{CaF_2}{3}$	ap.
	Fluorite	CaF_2	ft.
	Calcite	$CaO.CO_2$	cc.
	Pyrite	FeS_2	pr.

Of the minor inflexible molecules in the femic group magnetite, ilmenite, and apatite are very common. The others occur occasionally.

Among the femic minerals diopside, hypersthene, and olivine appear very often in the norm, acmite and wollastonite are not unusual, while ackermanite, potash metasilicate, and soda metasilicate are rare. Among the minor inflexible mineral molecules magnetite, ilmenite, and apatite commonly appear; hematite, titanite, perofskite, fluorite, and pyrite are not infrequently met with; and chromite, rutile, and calcite are rare.

The minor inflexible molecules, with the exception of magnetite and hematite, will not be considered at the outset. They are not present in the first eight of the series of calculated analyses, but were they present they would claim attention in the first place. Their calculation is simple, but the form of presentation gains in clearness by bringing them in only after the main features of the calculation have been dealt with. The key to the disposal to be made of the important oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, and K_2O lies in the relative affinities of K_2O, Na_2O, CaO, MgO, FeO, and Fe_2O_3, for SiO_2 and Al_2O_3. The point of prime importance is the amount of the two oxides SiO_2 and Al_2O_3. In the simpler cases K_2O, Na_2O, and CaO are to be allotted to Al_2O_3 and SiO_2 in the right proportions for the formation of the feldspars. K_2O has the strongest affinity for Al_2O_3 and SiO_2. It therefore has the first claim, and, after it has taken its quota of these oxides, Na_2O, with the next strongest affinity for them, receives its quota. Lastly CaO with an affinity less than the others is to be satisfied. The oxides MgO and FeO do not unite with both Al_2O_3 and SiO_2 at the same time in the normative minerals. They combine with SiO_2 alone to form hypersthene and olivine, or with CaO and SiO_2 to form diopside.

In Analysis A the simplest possible case is given. SiO_2 and Al_2O_3 are abundant, occurring in sufficient amounts to answer every claim of K_2O, Na_2O, and CaO upon them. Al_2O_3 remaining over is corundum, and SiO_2 remaining over is quartz. TiO_2 and P_2O_5 are not present, and no other elements occur which should be calculated as the minor inflexible mineral molecules. Fe_2O_3, FeO, and MgO not being present, there is nothing to be allotted for femic minerals.

In accordance with its formula $K_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, for orthoclase, K_2O, 53, takes 53 Al_2O_3 and six times as much SiO_2. In the same way albite, $Na_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, with Na_2O, 60, takes 60 molecular-proportion units of Al_2O_3 and 6×60 of SiO_2. Anorthite, $CaO.Al_2O_3.2SiO_2$, in the proportions 1:1:2, is made with 20 CaO, 20 Al_2O_3, and 40 SiO_2. Of Al_2O_3, 3 molecular-proportion units are left for corundum. Of SiO_2, 557 molecular-proportion units are left to form quartz. The percentage weights for the calculated minerals have been obtained from the second set of tables, pages 247–59, by looking up for orthoclase (or), the amount of K_2O, 53; for albite (ab), the amount of

ANALYSIS A

TOSCANOSE (APLITE). *Professional Paper 14*, p. 172, No. 122

Dargo, Victoria, Australia

Percentage	SiO_2 76.48	Al_2O_3 13.94	Fe_2O_3 Trace	FeO None	MgO 0.01	CaO 1.08	Na_2O 3.70	K_2O 4.90	H_2O 1.01	Sum 101.12	
Molecular Proportions	1.275	.136				.020	.060	.053	Salic Minerals		Femic Minerals
	318	53						53	or	29.5	
	360	60					60		ab	31.4	
	40	20				20			an	5.6	
		3							C	.3	
	557								Q	33.4	
	NOTE.—or .053×556=29.468 written as 29.5								Sal.	100.2	
	ab .060×524=31.440 written as 31.4								H_2O	1.01	
	an .020×278= 5.560 written as 5.6										
	C .003×102= .306 written as .3								Sum	101.21	
	Q .557× 60=33.420 written as 33.4										

Na_2O, 60; for anorthite (an), the amount of CaO, 20; for corundum (C), the amount of Al_2O_3, 3. To get quartz we multiply the amount of SiO_2 left over for it (557), by 60, the molecular weight of quartz. With abundant silica then and with Al_2O_3 greater than K_2O+Na_2O+CaO we make orthoclase, albite, anorthite, corundum with extra Al_2O_3, and quartz with extra SiO_2.

The sum of the percentage figures of the analysis, H_2O being 1.01, is 101.12. The sum of the calculated minerals in the norm with H_2O added in is 101.21, and for every calculated analysis these two should correspond as closely as 1 per cent. or 2 per cent. The correspondence cannot be numerically absolute, but it gives us a valuable check on the correctness of the calculation.

In Analysis B we have the same condition, except that FeO and Fe_2O_3 are both present. After the allotment for the feldspars has been made, and Al_2O_3 remaining over has been given to corundum (C), Fe_2O_3 and FeO, in the proportion 1:1, are allotted to magnetite (mt), and silica remaining over is quartz (Q).

ANALYSIS B

TEHAMOSE (QUARTZ PORPHYRY). *Professional Paper 14*, p. 132, No. 10

Tamaya, Chile

Percentage	SiO_2 75.93	Al_2O_3 13.26	Fe_2O_3 1.47	FeO 0.68	MgO None	CaO 1.11	Na_2O 3.13	K_2O 3.19	H_2O 0.44	Sum 99.72	
Molecular Proportions	1.266	.130	.009	.010		.020	.050	.034	Salic Minerals		Femic Minerals
	204	34						34	or	18.9	
	300	50					50		ab	26.2	
	40	20				20			an	5.6	
		26							C	2.7	
			9	9							mt 2.1
	722								Q	43.3	
	NOTE.—1 FeO neglected.								Sal. 96.7 Fem. 2.1 H_2O .44		Fem. 2.1
									Sum 99.24		

The calculation of Analysis C is like the preceding one in its allotments for orthoclase (or), albite (ab), anorthite (an), corundum (C), and magnetite (mt). Then there remain over, besides SiO_2, 2 molecular-proportion units of MgO, and 15 of FeO. These are allotted to hypersthene (hy), $(MgFe)O.SiO_2$, in the proportion $(MgFe)O:SiO_2$ as 1:1. MgO and FeO are used in hypersthene in the ratio in which they happen to stand when this mineral comes to be made. Here the ratio is 2:15. In later analyses MgO and FeO will be introduced into the calculations in the minerals diopside (di), and olivine (ol), as well as in hypersthene. When all three or any two of them are to be made MgO and FeO are to stand in all of them in the same proportion in which they were used in the first of these minerals calculated at the time. In Analysis C it will be noted that hypersthene is the sum of two parts, $MgO.SiO_2$ and $FeO.SiO_2$, each of which is to be found separately. $FeO.SiO_2$ may be looked up in the table on p. 254. $MgO.SiO_2$ is equal to 100 times the amount of MgO. These findings are added together for hypersthene.

ANALYSIS C

ALASKASE (RHYOLITE). *Professional Paper 14*, p. 130, No. 1

Madison Plateau, Yellowstone National Park

Percentage	SiO_2 75.19	Al_2O_3 13.77	Fe_2O_3 0.61	FeO 1.37	MgO 0.00	CaO 0.68	Na_2O 3.83	K_2O 3.33	H_2O 0.65	Sum 99.83	
Molecular Proportions	1.253	.135	.004	.019	.002	.012	.061	.035	Salic Minerals		Femic Minerals
	210	35						35	or	19.5	
	366	61					61		ab	32.0	
	24	12				12			an	3.3	
		27							C	2.8	
			4	4							mt .9
	17			15	2						hy 2.2 { $MgO.SiO_2$ .200 / $FeO.SiO_2$ 1.98
	636								Q	38.2	
									Sal.	95.8	Fem. 3.1
									Fem.	3.1	
									H_2O	.65	
									Sum	99.55	

In Analysis D after the allotment for magnetite (mt), 3 molecular-proportion units of Fe_2O_3 are left over. These go in as hematite (hm). Then MgO, 4, and FeO, 0, are left over. They are used to make a hypersthene free from FeO. In like manner in other analyses hypersthene might be made of $FeO.SiO_2$, the other component $MgO.SiO_2$ not being available.

In analysis E the allotments are made for orthoclase (or), albite (ab), anorthite (an), and magnetite (mt). CaO remaining is allotted, with MgO, FeO, and SiO_2, to diopside (di), $CaO.(MgFe)O.2SiO_2$, the proportions of the constituents by the formula being 1:1:2. MgO and FeO together are equal to CaO, and are used in the proportion in which they are found when the mineral comes to be made. Here the ratio is 36:5, or nearly 7:1. The silica is twice the lime. MgO and FeO remaining are used for hypersthene (hy), still in the same ratio 7:1 (see p. 63, line 11). SiO_2 is allotted by hypersthene in amount equal to MgO+FeO.

It is to be noted that we cannot have diopside and corundum together in the norm.

Analysis F presents the case where K_2O is allotted with Al_2O_3 and SiO_2 to orthoclase (or), and Na_2O is allotted to Al_2O_3 and SiO_2 for albite (ab). Al_2O_3 remaining, 9 units, can satisfy only 9 units of CaO for anorthite (an). Then CaO remaining is allotted to diopside (di), as far as MgO and FeO are available. Of CaO 27 molecular-proportion units are still left. These take an equal amount of SiO_2 for wollastonite (wo), $CaO.SiO_2$, 1:1. It is clear that since MgO and FeO were not present in sufficient amounts to make diopside with all the lime, there remain none of these constituents for hypersthene or olivine. So then with wollastonite there will be no hypersthene or olivine.

We now come to Analysis G, in which with abundant SiO_2, the Al_2O_3 covers K_2O and partly covers Na_2O. Orthoclase (or), is made, and albite (ab), as far as the Al_2O_3 admits of it. Soda, Na_2O, 5 units, left over, there being no Al_2O_3 available for it, takes Fe_2O_3 and SiO_2 for acmite (ac), $Na_2O.Fe_2O_3.4SiO_2$, in the proportions, 1:1:4. It is clear that with acmite there will be no anorthite. After the allotment is made for magnetite (mt), the CaO takes MgO, FeO, and SiO_2 for diopside (di). The remaining MgO and FeO are used

ANALYSIS D

MAGDEBURGOSE (GRANITE). *Professional Paper 14*, p. 124, No. 3
Felch Mountain, Mich.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum	
Percentage	76.10	12.95	0.65	0.09	0.14	0.12	2.36	6.50	0.65	99.65	
Molecular Proportions	1.268	.127	.004	.001	.004	.002	.038	.069	Salic Minerals		Femic Minerals
	414	69						69	or	38.4	
	228	38					38		ab	19.9	
	4	2				2			an	.6	
		18							C	1.8	
			1	1							mt .2
			3								hm .5
	4			0	4						hy .4 $\begin{cases} MgO,SiO_2 & .400 \\ FeO,SiO_2 & .00 \end{cases}$
	618								Q	37.1	
									Sal.	97.8	Fem. 1.1
									Fem.	1.1	
									H_2O	.65	
									Sum	99.55	

ANALYSIS E

TOSCANOSE (GRANITE). *Professional Paper 14*, p. 168, No. 92
Riesengebirge, Silesia

Percentage	SiO_2 71.53	Al_2O_3 13.55	Fe_2O_3 1.20	FeO 0.88	MgO 1.45	CaO 3.21	Na_2O 2.61	K_2O 3.95	H_2O 1.75	Sum 100.13	
Molecular Proportions	1.192	.133	.007	.012	.036	.057	.042	.042	Salic Minerals		Femic Minerals
	252	42						42	or	23.4	
	252	42					42		ab	22.0	
	98	49				49			an	13.6	
			7	7							mt 1.6
	16			1	7	8					di 1.8 { $CaO.SiO_2$ .93; $MgO.SiO_2$ .700; $FeO.SiO_2$ .13
	33			4	29						hy 3.4 { $MgO.SiO_2$ 2.900; $FeO.SiO_2$ .53
	541								Q	32.5	
									Sal.	91.5	Fem. 6.8
									Fem.	6.8	
									H_2O	1.75	
									Sum	100.05	

ANALYSIS F

ALASKOSE (GRANITE). *Professional Paper 14*, p. 126, No. 4

Waushara, Wis.

Percentage	SiO_2 74.02	Al_2O_3 10.01	Fe_2O_3 3.85	FeO 1.72	MgO 0.33	CaO 2.43	Na_2O 3.33	K_2O 3.38	H_2O 0.24	Sum 99.91	
Molecular Proportions	1.244	.008	.024	.024	.008	.044	.053	.036	Salic Minerals		Femic Minerals
	216	36						36	or	20.0	
	318	53					53		ab	27.8	
	18	9				9			an	2.5	
			24	24							mt 5.6
	16			0	8	8					di 1.7 { $CaO.SiO_2$ .93; $MgO.SiO_2$ .800; $FeO.SiO_2$ .00
	27					27					wo 3.1
	649								Q	39.0	
									Sal.	89.3	Fem. 10.4
									Fem.	10.4	
									H_2O	.24	
									Sum	99.94	

ANALYSIS G

OMEOSE (LIPARITE). *Professional Paper 14*, at bottom of p. 142, No. 3

Cabo de Gata, Spain

Percentage	SiO_2 71.12	Al_2O_3 13.35	Fe_2O_3 1.37	FeO 1.28	MgO 0.47	CaO 0.32	Na_2O 2.02	K_2O 9.82	HO_2 1.13	Sum 100.88	
Molecular Proportions	1.185	.131	.009	.018	.012	.005	.032	.104	Salic Minerals		Femic Minerals
	624	104						104	or	57.8	
	162	27					27		ab	14.2	
	20		5				5				ac 2.3
			4	4							mt .9
	10			3	2	5					di 1.2 { $CaO.SiO_2$ .58; $MgO.SiO_2$ .200; $FeO.SiO_2$ .40
	21			11	10						hy 2.5 { $MgO.SiO_2$ 1.000; $FeO.SiO_2$ 1.45
	348								Q	20.9	
									Sal.	92.9	Fem. 6.9
									Fem.	6.9	
									H_2O	1.13	
									Sum	100.93	

for hypersthene (hy), in the same porportion in which they stood for diopside.

Analysis H presents the case where after making orthoclase (or), albite (ab), and acmite (ac), Na_2O still remains over. This is allotted with SiO_2 to form sodium metasilicate (ns), $Na_2O \cdot SiO_2$, 1:1. It is rarely found necessary to introduce sodium metasilicate in this way.

Case I presents the inflexible mineral molecules ilmenite, titanite, apatite, and fluorite. Sodium metasilicate is introduced, and potassium metasilicate (ks), $K_2O.SiO_2$, as well—an extremely rare occurrence. The minor inflexible molecules in the femic group are magnetite, chromite, hematite, ilmenite, titanite, perofskite, rutile, apatite, fluorite, calcite, and pyrite. Magnetite and hematite have been introduced in preceding analyses; chromite is made in Analysis S, perofskite in Analysis S, rutile is considered in the present analysis, calcite appears in Analysis O, and pyrite in Analysis K. In the salic group we have the minor inflexible molecules zircon, sodalite, and noselite. Zircon appears in Analysis M, and sodalite and noselite in Analysis O.

Following the order stated on p. 188, sec. 3, in the *Quantitative Classification of Igneous Rocks*, Cr_2O_3 not being present, we first allot FeO to TiO_2 for ilmenite (il), in the proportion 1:1. TiO_2 remaining over takes CaO and SiO_2 for titanite (tn), $CaO.TiO_2.SiO_2$, in the proportion 1:1:1. We are working with an analysis in which the amount of SiO_2 is sufficient to meet all claims upon it. If silica were not abundant TiO_2 remaining over after the allotment for ilmenite would take CaO for perofskite (pf), $CaO.TiO_2$, in the proportion 1:1. Such a case is given in Analysis S. Here if TiO_2 after the allotments for ilmenite and titanite still remained over, it would be considered as rutile (ru), TiO_2. In the next place P_2O_5 takes $3\frac{1}{3}$ times as many units of CaO as there are units of P_2O_5, and $\frac{1}{3}$ as much F or Cl, for apatite (ap), $3CaO.P_2O_5+\frac{CaCl_2}{3}$ or $3CaO.P_2O_5+\frac{CaF_2}{3}$ in the ratio $CaO:P_2O_5$ as $3\frac{1}{3}$:1, and F or Cl, to satisfy CaO, equal to $\frac{1}{3}P_2O_5$. In the next place fluorine (F=26), takes $\frac{1}{2}$ as much CaO for fluorite (ft), CaF_2. After these minor inflexible molecules have been adjusted K_2O is allotted for orthoclase with the

ANALYSIS H

VARINGOSE (PANTELLERITE). *Professional Paper 14*, p. 218, No. 4

Pantelleria

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum	
Percentage	70.30	6.32	9.23	1.40	0.89	0.84	7.70	2.50	0.82	100.00	
Molecular Proportions	1.172	.062	.058	.019	.022	.015	.124	.026	Salic Minerals		Femic Minerals
	156	26						26	or	14.5	
	216	36					36		ab	18.9	
	232		58				58				
	30						30				ac 26.8
											ns 3.7
	30			7	8	15					di 3.5 { $CaO.SiO_2$ 1.74; $MgO.SiO_2$ .800; $FeO.SiO_2$ .92
	26			12	14						hy 3.0 { $MgO.SiO_2$ 1.400; $FeO.SiO_2$ 1.58
	482								Q	28.9	
									Sal.	62.3	Fem. 37.0
									Fem.	37.0	
									H_2O	.82	
									Sum	100.12	

ANALYSIS 1

ORENDOSE (ORENDITE). *Professional Paper 44*, p. 312, No. 2

Leucite Hills, Wyom.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Ka_2O	K_2O	TiO_2	P_2O_5	Cl	F	H_2O	Sum
Percentage	54.08	9.49	3.19	1.03	6.74	3.55	1.39	11.76	2.08	1.35	0.04	0.49	3.50	99.76
Molecular Proportions	.901	.093	.020	.014	.169	.063	.022	.145	.026	.009	.001	.026		

Salic Minerals		Femic Minerals	
		il	2.1
		tn	2.4
		ap	3.0
		ft	1.0
or	51.7		
		ks	4.9
		ac	9.2
		ns	.2
		di 1.7	$CaO.SiO_2$ .93; $MgO.SiO_2$ .800; $FeO.SiO_2$ .00
		hy 16.1	$MgO.SiO_2$ 16.000; $FeO.SiO_2$ .00
Q	2.4		
Sal.	54.1	Fem.	40.6
Fem.	40.6		
H_2O	3.50		
Sum	98.20		

	12			14		12			14					
						30			12					
	558	93				13				9	1	26		
	32							93						
	80		20					32						
	2						20							
							2							
	16			0	8	8								
	161			0	161									
	40													

available Al_2O_3, 93, and SiO_2. The K_2O remaining over is allotted to potassium metasilicate (ks), $K_2O.SiO_2$, with SiO_2, in the ratio 1:1. After all the K_2O has been used Na_2O takes Fe_2O_3, as far as Fe_2O_3 is available (there being no Al_2O_3 left to unite with it), and SiO_2, for acmite. Na_2O still remaining over is sodium metasilicate. CaO remaining after the foregoing assignments takes MgO and FeO in the requisite amounts, and in the ratio in which they stand, 8:0, for diopside (di). MgO remaining, there being no FeO, is allotted to hypersthene, and the SiO_2 which has not been used is quartz.

All the analyses thus far presented, from A to I inclusive, have been those in which SiO_2 is abundant. The calculation of analyses in which SiO_2 is relatively low is usually more difficult. Orthoclase (or), $K_2O.Al_2O_3.6SiO_2$, requires more silica than leucite (lc), $K_2O.Al_2O_3.4SiO_2$, and leucite requires more silica than kaliophilite (kp), $K_2O.Al_2O_3.2SiO_2$. In the same way albite (ab), $Na_2O.Al_2O_3.6SiO_2$ requires more silica than nephelite (ne), $Na_2O.Al_2O_3.2SiO_2$. It should be noted that the ratio between K_2O and Al_2O_3 is always as 1:1 in orthoclase, leucite, and kaliophilite, and that the ratio between Na_2O and Al_2O_3 is always 1:1 in albite and nephelite. Hypersthene (hy), $(MgFe)O.SiO_2$ requires more silica than olivine (ol), $2(MgFe)O.SiO_2$, for the same amount of (MgFe)O. With low silica, therefore, a substitution is made of one or more minerals which require less silica than the minerals employed in the straightforward calculations thus far considered.

Where silica is low the simplest adjustment is that illustrated by Analysis J. Here the minor inflexible molecules, ilmenite (il), and apatite (ap), are first calculated. In this analysis apatite cannot get its quota of Cl or F, for these elements have not been determined. The molecular weight is however taken as 336, and the percentage weight of the mineral obtained by multiplying the amount of P_2O_5 by 336. The table on p. 258 for the percentage weights of apatite is based on a molecular weight of 336, F or Cl having been available. Al_2O_3 is present in sufficient amount to allow with silica for the formation of orthoclase (or), albite (ab), and anorthite (an). After the allotments for magnetite (mt), and diopside (di), there remain of MgO 67, and of FeO 20 units. The silica available at this point is 62. This is not enough to make hypersthene with the MgO and

FeO, for which 87 molecular proportion units of SiO_2 would be needed. If we should take the MgO and FeO with silica for olivine (ol), $2(MgFe)O.SiO_2$, in the proportion 2:1, then silica would be left over in amount equal to 18 units. The formulated method for calculating the norm does not admit of our making olivine at this point with (MgFe)O and silica, and then calling the remaining silica quartz. This accords with the fact that quartz and olivine are very rarely found together in igneous rocks. What we do is to divide the MgO, FeO, and available silica between hypersthene and olivine, making use of two simple algebraic equations.

Let x = the number of hypersthene molecules
and y = the number of olivine molecules;
then $x+y$ = the number of units of (MgFe)O

and $x+\frac{y}{2}$ = the number of units of SiO_2,

or $x+y=87$

and $x+\frac{y}{2}=62$

$\frac{y}{2}=25$

$y=50$ = molecules of olivine
and $x=37$ = molecules of hypersthene.

MgO and FeO are to be introduced in hypersthene and in olivine in the same ratio in which they were used in diopside. The ratio in this case is 20:67 or, nearly, $1:3\frac{1}{3}$.

It is to be noted in connection with the use of the tables that olivine is the sum of two parts, $2MgO.SiO_2$ and $2FeO.SiO_2$. We look up the first of these on p. 255, and use in looking it up one-half the amount of MgO units, i. e., $\frac{39}{2}$, not 39.; and in the same way we look up one-half the amount of FeO units, or $5\frac{1}{2}$, not 11, on p. 256, and add our findings together for olivine.

Analysis K illustrates the same points as J, but in it pyrite is introduced, FeS_2 having been present in the rock.

x = the number of hypersthene molecules
y = the number of olivine molecules
$x+y=139=(MgFe)O$
$x+\frac{y}{2}=88=SiO_2$
$\frac{y}{2}=51$, $y=102$, and $x=37$.

ANALYSIS J

ANDOSE (DIORITE). *Professional Paper 14*, p. 272, No. 11

Crazy Mountains, Mont.

Percentage	SiO_2 50.73	Al_2O_3 19.09	Fe_2O_3 3.20	FeO 4.66	MgO 3.48	CaO 8.55	Na_2O 4.03	K_2O 1.89	TiO_2 1.59	P_2O_5 0.81	H_2O .077	Sum 100.13	
Molecular Proportions	.846	.196	.020	.066	.087	.155	.065	.020	.030	.006	Salic Minerals		Femic Minerals
	120	20		20		18		20	20	6			il 3.0
	390	65					65						ap 2.0 .006×336
	222	111				111					or 11.1		
			20	20							ab 34.1		
											an 30.9		
													mt 4.6
	52			6	20	26							di 5.8 { $CaO.SiO_2$ 3.02; $MgO.SiO_2$ 2.000; $FeO.SiO_2$ .79
Remainder at this point →													
SiO_2 62													
MgO 67				9	28								
FeO 20	37												hy 4.0 { $MgO.SiO_2$ 2.800; $FeO.SiO_2$ 1.19
	25			11	39								ol 3.9
											Sal. 76.1		Fem. 23.3
											Fem. 23.3		
											H_2O .77		
											Sum 100.17		

NOTE.—With FeO, MnO .001 has been added in. BaO, .002 have been added to CaO.

ANALYSIS K

HESSOSE (AMPHIBOLE GABBRO). *Classification of Igneous Rocks*, p. 199

Big Trees Quadrangle, Cal.

Percentage	SiO_2 47.27	Al_2O_3 20.82	Fe_2O_3 1.85	FeO 4.26	MgO 6.44	CaO 13.02	Na_2O 2.75	K_2O 0.22	TiO_2 0.92	P_2O_5 0.74	FeS_2 0.20	H_2O 1.35	Sum 99.84		
Molecular Proportions	.788	.204	.011	.059	.161	.232	.044	.002	.011	.005		Salic Minerals		Femic Minerals	
				11		15			11	5				ap	1.6
	12	2						2						il	1.7
	246	44					44					or	1.1		
	306	158				158						ab	23.1		
			11	11								an	43.9		
														mt	2.6
	118			11	48	59								di	13.1 CaO.SiO_2 6.84; MgO.SiO_2 4.800; FeO.SiO_2 1.45
	37			7	30									hy	3.9 MgO.SiO_2 3.000; FeO.SiO_2 .92
	51			19	83									ol	7.7 2MgO.SiO_2 5.80; 2FeO.SiO_2 1.94
												Sal.	68.1	FeS_2	.2
												Fem.	30.8		
												H_2O	1.35	Fem.	30.8
												Sum	100.25		

It is to be noted that with quartz we will not have olivine in the norm and vice versa.

By making some hypersthene and some olivine, therefore, we can allow for a small shortage of SiO_2. If we attempt to calculate Analysis L in the same manner it is found that after making orthoclase (or), albite (ab), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), 219 more units of silica have been called for than are available. The silica deficit is too great to be treated as in the preceding example.

ANALYSIS L. TENTATIVE

LAURDALOSE (SYENITE PEGMATITE). *Professional Paper 14*, p. 296, No. 14
Stoksund, Norway

Percentage	SiO_2 53.81	Al_2O_3 19.69	Fe_2O_3 .620	FeO .363	MgO .085	CaO .173	Na_2O 7.77	K_2O 4.58	H_2O 1.52	Sum 99.78	
Molecular Proportions	.897	.193	.039	.050	.021	.031	.125	.049		Salic Minerals	Femic Minerals
	294	49						49		or	
	750	125					125			ab	
	38	19				19				an	
			39	39							mt
	24			4	8	12					di
	10			7	13						ol
	1,116 SiO_2 have been allotted at this point.										
	897 available SiO_2										
	219 SiO_2 deficit for this distribution										

In the tentative distribution albite (ab) calls for 6×125, or 750, SiO_2. Nephelite would use up only 250, or 2×125, SiO_2. If we allot in the first place (holding out the soda, Na_2O, 125, and equal Al_2O_3, 125) the proper amounts of the various oxides for orthoclase (or), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), we shall have 531 units of SiO_2 left, to go with the 125 Na_2O and 125 Al_2O_3. What we do then is to make a certain amount of albite and a certain amount of nephelite. It is to be remembered that in any allotment of Na_2O and Al_2O_3 to albite (ab), $Na_2O.Al_2O_3.6SiO_2$, and nephelite (ne), $Na_2O.Al_2O_3.2SiO_2$, the ratio of Na_2O to Al_2O_3 will be as 1:1. Being silica poor we made olivine (ol), with (MgFe)O and not hypersthene. The formulas for the distribution of Na_2O, Al_2O_3, and SiO_2 between albite and nephelite are as follows:

Let x = the number of albite molecules
Let y = the number of nephelite molecules
then $x+y=Na_2O=Al_2O_3$
and $6x+2y=SiO_2$
$x+y=125$
$6x+2y=531$
$2x+2y=250$
subtracting $4x=281$
$x=70$ molecules of albite
$y=55$ molecules of nephelite.

It is clear that with nephelite in the norm we shall not have quartz.

Analysis M proceeds on the same lines as L except that the minor inflexible molecule zircon (Z), is first introduced, taking $ZrO_2=SiO_2$ in accordance with its formula $ZrO_2.SiO_2$.

In N we have a case with SiO_2 still lower than in M. If we attempt to calculate it in the same way as L and M we find that we have run over on SiO_2 by 21 units, holding out $Na_2O.Al_2O_3$, 45, for albite and nephelite, and making the allotments for apatite, orthoclase, anorthite, magnetite, diopside, and olivine. We have therefore no SiO_2 with which to make even nephelite with the 45 $Na_2O.Al_2O_3$ held out in the beginning.

There is not enough SiO_2 therefore to begin the calculation by making orthoclase. This case is analogous to the situation in L and M where Na_2O is distributed between albite and nephelite. We proceed by holding out all the K_2O and equal Al_2O_3 for a certain amount of orthoclase, and a certain amount of leucite ($K_2O.Al_2O_3.4SiO_2$), which calls for less SiO_2 than orthoclase does. These minerals will each use up K_2O and Al_2O_3 in the ratio 1:1. The Na_2O is allotted with Al_2O_3 and SiO_2 to nephelite. This is much lower in SiO_2 than albite is. Anorthite, magnetite, diopside, and olivine are then made. The SiO_2 remaining over is 369. This is given to the $K_2O.Al_2O_3$, previously set aside, for orthoclase and leucite, by means of the equations where

x = the number of molecules of orthoclase
and y = the number of molecules of leucite
$x+y=K_2O$
and $6x+4y=SiO_2$
Here $x+y=80$
$6x+4y=369$
$x=24$
and $y=56$.

ANALYSIS L

LAURDALOSE (SYENITE PEGMATITE). *Professional Paper 14*, p. 296, No. 14

Stoksund, Norway

Percentage	SiO_2 53.81	Al_2O_3 19.69	Fe_2O_3 6.20	FeO 3.63	MgO 0.85	CaO 1.73	Na O 7.77	K_2O 4.58	H_2O 1.52	Sum 99.78	
Molecular Proportions	.897	.193	.039	.050	.021	.031	.125	.049	Salic Minerals		Femic Minerals
	294	49						49	or	27.2	
	420	125 { 70					125 { 70		ab	36.7	
	110	125 { 55					125 { 55		ne	15.6	
	38	19				19			an	5.3	
			39	39							mt 9.1
	24			4	8	12					di 2.7 { $CaO.SiO_2$ 1.39; $MgO.SiO_2$ .800; $FeO.SiO_2$ .53
	10			7	13						ol 1.6 { $2MgO.SiO_2$ .91; $2FeO.SiO_2$ .71
	896								Sal. 84.8		Fem. 13.4
									Fem. 13.4		
									H_2O 1.52		
									Sum 99.72		

ANALYSIS M

Lujavrose (Lujaurite). *Professional Paper 14*, p. 303, last section, No. 1
Kangerdluarsuk, Greenland

Percentage	SiO_2 51.62	Al_2O_3 15.03	Fe_2O_3 6.06	FeO 4.98	MgO Tr	CaO 3.45	Na_2O 10.09	K_2O 4.19	ZrO_2 2.14	H_2O 2.12	Sum 100.61	
Molecular Proportions	.860	.153	.038	.069		.062	.103	.045	.017	Salic	Minerals	Femic Minerals
	17								17	z	3.1	
	270	45						45		or	25.0	
	90	108 { 15					108 { 15			ab	7.9	
	180	93					93			ne	26.4	
	152		38				38					
	17						17					ac 17.6
												ns 2.1
	124			62	0	62						di 15.4 { $CaO.SiO_2$ 7.19; $MgO.SiO_2$ .000; $FeO.SiO_2$ 8.18
	4			7	0							ol .7 { $2MgO.SiO_2$ .00; $2FeO.SiO_2$ .71
										Sal. 62.4		Fem. 35.8
										Fem. 35.8		
										H_2O 2.12		
										Sum 100.32		

ANALYSIS N. TENTATIVE

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

Percentage	SiO_2 47.65	Al_2O_3 19.28	Fe_2O_3 2.63	FeO 6.48	MgO 4.19	CaO 9.01	Na_2O 2.78	K_2O 7.47	P_2O_5 0.50	H_2O 0.24	Sum 100.23	
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals		Femic Minerals
	480	80				12		80	4			ap
		45					45			or		
										ab		
	128	64				64				ne		
			16	16						an		
	170			40	45	85						mt
	37			34	40							di
	815											ol
	794											
	21	SiO_2										

With leucite and nephelite there will be no quartz nor will there be hypersthene. With leucite in the norm there will be no albite.

ANALYSIS N

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

Percentage	SiO_2 47.65	Al_2O_3 19.28	Fe_2O_3 2.63	FeO 6.48	MgO 4.19	CaO 9.01	Na_2O 2.78	K_2O 7.47	P_2O_5 0.50	H_2O 0.24	Sum 100.23		
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals			Femic Minerals
						12			4			ap	1.3
	144	80 24						80 24		or	13.3		
	224	56						56		lc	24.4		
	90	45					45			ne	12.8		
	128	64				64				an	17.8		
			16	16								mt	3.7
	170			40	45	85						di	19.6
	37			34	40							ol	6.3
										Sal.	68.3	Fem.	30.9
										Fem.	30.9		
										H_2O	.24		
										Sum	99.44		

Analysis O is like N, where K_2O goes partly to orthoclase and partly to leucite, but here we make the minor inflexible molecules

ANALYSIS O

JANEIROSE (PSEUDO-LEUCITE-SODALITE-TINGUAITE). *Classification of Igneous Rocks*, p. 203

Bearpaw Mountains, Mont.

Percentage	SiO_2 51.93	Al_2O_3 20.29	Fe_2O_3 3.59	FeO 1.20	MgO 0.22	CaO 1.65	Na_2O 8.49	K_2O 9.81	TiO_2 0.20	SO_3 0.67	CO_2 0.25	Cl 0.70	F 0.27	H_2O 1.09	Sum 100.31	
Molecular Proportions	.866	.200	.022	0.18	.066	BaO .030 .001 SrO .001 .001 .032	.137	.104	.002	.009	.006	.020	.014	Salic Minerals		Femic Minerals
Note				2		7	10		2				14			il .3 ft .6
						6	9			9		20		so 9.7 no 6.3		
	390	104 { 65						104 { 65			6			or 36.1		cc .6
	156	{ 39						{ 39						lc 17.0		
	192	96					96							ne 13.6		
	88		22				22									ac 10.2
						19										di 4.3 { $CaO.SiO_2$ 1.97 { $MgO.SiO_2$ .500 { $FeO.SiO_2$ 1.85
	38			14	5											
	2			2	1											ol .3 { $2MgO.SiO_2$ .07 { $2FeO.SiO_2$ .20
	Sodalite (so) equals .010×969, or 9.69 Noselite (no) equals .009×699, or 6.29													Sal. 82.7 Fem. 16.3 H_2O 1.09 Sum 100.09		Fem. 16.3

NOTE.—The allotments of SiO_2 and Al_2O_3 to the nephelite ($Na_2O.Al_2O_3.2Si_2O$) element in sodalite and noselite have been summed with nephelite 96 ($Na_2O.Al_2O_3.2SiO_2$).

ilmenite (il), fluorite (ft), sodalite (so), noselite (no), and calcite (cc), at the outset. (See note at end of paper.) The formula for sodalite is $3(Na_2O.Al_2O_3.2SiO_2).2NaCl$ and that for noselite is $2(Na_2O.Al_2O_3.2SiO_2)Na_2SO_4$. Sodalite is therefore like the nephelite molecule taken three times with 2NaCl added. Where Cl occurs in notable amount with P_2O_5 present it is first allotted to apatite (see Analysis I), and the remainder then takes half as many units of Na_2O for 2NaCl in sodalite. One-half the number of units of Cl is the key. By multiplying this number, .010, by 969 (the molecular weight of sodalite), the percentage weight of sodalite (so) is obtained. Where SO_3 is present it takes an equal amount of Na_2O for Na_2SO_4 in noselite (no). The number of units of SO_3 is the key. By multiplying this number, .009, by 699 (the molecular weight of noselite), we get the percentage weight of noselite. In this calculation the nephelite molecules in sodalite (15), and in noselite (9), have been lumped in with nephelite. CO_2 when present in a rock usually points to a weathered condition in the rock, the mineral then being present as an alteration product. Where CO_2 occurs in a rock and is not a product of alteration, calcite is an original mineral constituent. In Analysis O we allot to 6 units of CO_2 as many units of CaO for calcite (cc), $CaO.CO_2$, the ratio between CaO and CO_2 being 1:1.

In the foregoing examples of calculation a shortage of SiO_2 was met by distributing $Na_2O.Al_2O_3$ between albite and nephelite, after making orthoclase with $K_2O.Al_2O_3$; or the shortage was provided against, after making nephelite, by distributing $K_2O.Al_2O_3$ between orthoclase and leucite. With SiO_2 too low for either of these alternatives we may allot $K_2O.Al_2O_3$ to leucite and $Na_2O.Al_2O_3$ to nephelite, using up in this way a relatively small amount of SiO_2. This is the procedure in Analysis P, where we make leucite, nephelite, anorthite, magnetite, diopside, and olivine, only to find that we have run over by 74 units of SiO_2. In making diopside we used 302 SiO_2. If now we take CaO from diopside, turn the MgO and FeO thus set free into more olivine, and use the lime (with the requisite amount of SiO_2) in ackermanite (am), $4CaO.3SiO_2$, which by its formula uses up less SiO_2 for the same amount of CaO than diopside does, we can do away with the SiO_2 deficit. When the ratios of $CaO:SiO_2$ in diopside, 1:2 (or 4:8), and in ackermanite, 4:3, are considered, it

ANALYSIS P. TENTATIVE

ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1
Alban Hills, Italy

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O	Sum	
Percentage	45.00	17.12	4.17	5.38	5.30	10.47	2.18	8.07	0.37	0.45	100.65	
Molecular Proportions	.767	.168	.026	.075	.133	.187 .002 BaO .189	.035	.005	.005	Salic Minerals		Femic Minerals
				5					5			il
	380	95						95		lc		
	70	35					35			ne		
	76	38				38				an		
			26	26								mt
	302			38	113	151						di
	13			6	20							ol
	841											
	767											
	74 Deficit in SiO_2											

at once appears that ackermanite (am), is the mineral lower in SiO_2 for the same amount of CaO. By taking 96 CaO from the diopside and using with it 72 SiO_2 we make 24 molecules of ackermanite, i. e., 24 ($4CaO.3SiO_2$). By recalculating for new diopside and putting in the 24 molecules of ackermanite (am) (calling for 72 SiO_2 with 96 CaO), we find that as the result there is no deficit of SiO_2. To ascertain just the right amount of ackermanite to be introduced we make use of the simple formula where

y = the deficit of SiO_2

$\frac{y}{3}$ = the number of ackermanite molecules to be made.

It appears on trial of all such cases that the deficiency in SiO_2 is exactly allowed for when the number of ackermanite molecules made with CaO taken from diopside equals one-third of the SiO_2 deficit, and in consequence we take lime away from diopside equal to four times the number of ackermanite molecules. Numerically it is found that for every unit of CaO taken from diopside and used in ackermanite we gain three-fourths of a unit in silica, though the process involves the making of new olivine which itself uses up silica. So then to make up a deficit of 74 SiO_2 we need to take 96 CaO from diopside, 96 CaO + 72 SiO_2 making 24 molecules of ackermanite.

In P, therefore, we first allot for ilmenite, leucite, nephelite, anorthite, and magnetite. Then, for ackermanite, 96 CaO units are taken from diopside previously made, and used with 72 SiO_2 for ackermanite in accordance with the formula $4CaO.3SiO_2$. In looking up the percentage weight of ackermanite (am), in the table on p. 256 the unit of calculation is 24, not 96; i. e., it is one-fourth the molecular proportion of CaO in the ackermanite. The 55 units of CaO left over from the original diopside assignment are allotted for new diopside, and the MgO and FeO thus set free go to olivine.

It should be noted that in this analysis after making diopside there is no excess of CaO to be set aside for the making of wollastonite (cf. Analysis F). In the following example (Q), 95 molecular-proportion units of CaO are left over after the making of diopside for wollastonite.

The calculation of Analysis Q differs from that of the preceding example, as was noted just above, in that CaO in the tentative allotment is found to cover the MgO and FeO for diopside and to remain over after this in amount equal to 95 units. These are given to wollastonite (wo), $CaO.SiO_2$. The silica deficit is 78. By turning 92 of the 95 CaO of the wollastonite into ackermanite (making in such a case 23 molecules of ackermanite calling for 92 CaO and 69 SiO_2), we can do away with a deficit of silica equal to 23. If then our silica deficit were not 78 as it is in this analysis but only 23 or less, enough CaO set aside for wollastonite could be converted into ackermanite in this manner to do away with the silica deficit. The formula used is, where y = the silica deficit, y = as well the number of ackermanite molecules to be made. This alternative is not open to us in this analysis but it is clear how such calculations are to be treated when they arise. In this case, with insufficient molecules of wollastonite to satisfy the deficit of SiO_2 by their conversion into ackermanite, the molecules of both diopside and wollastonite are to be recalculated to make new diopside, new olivine, and ackermanite by the following equations.

Let x = the molecules of new diopside
y = the molecules of ackermanite
z = the molecules of new olivine.

Then $2x+3y+\frac{z}{2}$ = the available SiO_2
$x+4y$ = the available CaO
$x+z$ = the available (MgFe)O.

ANALYSIS P

ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1

Alban Hills, Italy

Percentage	SiO_2 45.90	Al_2O_3 17.12	Fe_2O_3 4.17	FeO 5.38	MgO 5.30	CaO 10.47	Na_2O 2.18	K_2O 8.97	TiO_2 0.37	H_2O 0.45	Sum 100.65	
Molecular Proportions	.767	.168	.026	.075	.133	.187 CaO .002 BaO .189	.035	.095	.005	Salic Minerals		Femic Minerals
	380	95		5				95	5	lc 41.4		il .8
	70	35					35			ne 9.9		
	76	38				38				an 10.6		
	72		26	26		96						mt 6.0
												am 9.7
	110			14	41	55						di 12.3 { $CaO.SiO_2$ 6.38; $MgO.SiO_2$ 4.100; $FeO.SiO_2$ 1.85
	61			30	92							ol 9.5 { $2MgO.SiO_2$ 6.44; $2FeO.SiO_2$ 3.06
										Sal. 61.9		Fem. 36.3
										Fem. 36.3		
										H_2O .45		
										Sum 98.65		

ANALYSIS Q

COVOSE (NEPHOLITE SYENITE). *Professional Paper 14*, p. 352, No. 2

Magnet Cove, Ark.

Percentage	SiO_2 38.93	Al_2O_3 15.41	Fe_2O_3 5.10	FeO 4.24	MgO 5.57	CaO 16.49	Na_2O 5.27	K_2O 1.78	TiO_2 1.02	P_2O_5 0.35	H_2O 5.02	Sum 100.57			
Molecular Proportions	.649	.151	.032	.059	.139	.294	.085	.019	.020	.002	Salic Minerals		Femic Minerals		Tentative
						6				2			ap .7		
				20					20				il 3.0		
	76	19						19			lc 8.3				
	170	85					85				ne 24.1				
	94	47				47					an 13.1				
			32	32									mt 7.4		
Tentative →	(292)			(7)	(139)	(146)									di
Tentative	(95)					(95)									wo
Note															
	146			4	69	73							di 15.9	CaO.SiO_2 8.47; MgO.SiO_2 6.900; FeO.SiO_2 .53	
	36			3	70								ol 5.2	2MgO.SiO_2 4.90; 2FeO.SiO_2 .30	
	126														
	168					168							am 17.0		
											Sal. 45.5		Fem. 49.2		
											Fem. 49.2				
											H_2O 5.20				
											Sum 99.9				

NOTE.—A deficit of 78 SiO_2 results from this tentative assignment.

In this calculation the available SiO_2 is 309, the CaO 241, and the (MgFe)O, 146.

Therefore (1) $2x+3y+\frac{z}{2}=309$

(2) $x+4y=241$

and (3) $x+z=146$.

From (2), multiplying by 2,

$2x+8y=482$;

(1) $2x+3y+\frac{z}{2}=309$;

subtracting $5y-\frac{z}{2}=173$

or $10y-z=346$.

Again (2) $x+4y=241$

(3) $x+z=146$;

subtracting $4y-z=95$

$10y-z=346$

$4y-z=95$

$y=42$, ackermanite

$x=73$, new diopside

$z=73$, new olivine.

With silica still lower than in Analysis Q we make such a calculation as is given in Analysis R. Here, after the assignment for ilmenite the K_2O, 79 units, is held out with equal $Al_2O_3.Na_2O$, takes Al_2O_3 as far as it is available (17), and SiO_2 for nephelite. Extra Na_2O, 9, takes Fe_2O_3 and SiO_2 for acmite. Fe_2O_3 remaining takes equal FeO for magnetite. All the CaO, 296 units, is calculated as ackermanite, and MgO and FeO remaining over take SiO_2 for olivine. Silica is left equal to 204 units. This is distributed with the 79 $K_2O.Al_2O_3$ held out (ante), between leucite and kaliophilite (kp), $K_2O.Al_2O_3.2SiO_2$. The equations are

$x+y=K_2O$

$4x+2y=SiO_2$

where x = the number of molecules of leucite

and y = the number of molecules of kaliophilite.

(1) $x+y=79$, K_2O

(2) $4x+2y=204$, SiO_2.

From (1) $2x+2y=158$

$2x=46$

$x=23$, leucite molecules

$y=56$, kaliophilite molecules.

Kaliophilite takes only half as much silica to go with a like amount of $K_2O.Al_2O_3$ as leucite would take, and only a third as much as orthoclase.

ANALYSIS R

VENANZOSE (EUKTOLITE). *Professional Paper 14*, p. 357, last analysis
San Venanzo, Umbria, Italy

Percentage	SiO_2 41.43	Al_2O_3 9.80	Fe_2O_3 3.28	FeO 5.15	MgO 13.40	CaO 16.62	Na_2O 1.64	K_2O 7.40	TiO_2 0.29	H_2O 1.11	Sum 100.12	
Molecular Proportions	.691	.096	.021	.072	.335	.296	.026	.079	.004	Salic Minerals		Femic Minerals
				4					4			il .6
	92	79 { 23						79 { 23		lc 10.0		
	112	79 { 56						79 { 56		kp 17.7		
	34	17					17			ne 4.8		
	36		9				9					ac 4.2
			12	12								mt 2.8
	222					296						am 29.1
	195			56	335							ol 29.2
										Sal. 32.5		Fem. 65.9
										Fem. 65.9		
										H_2O 1.11		
										Sum 99.51		

It will be noted that the series of analyses from J to R inclusive illustrates a series of alternative methods for dealing with low SiO_2. A slight deficit may be adjusted between hypersthene and olivine. By this device we can do away with a silica deficit equal to one-half (MgFe)O. A larger deficit may be provided against by making albite with nephelite after having made orthoclase, under the conditions given above. This saving of silica amounts to a little less than four times the Na_2O. A still larger deficiency in SiO_2 may be provided for by allotting for orthoclase and leucite after making nephelite. Our making nephelite first in this case saves us an amount of SiO_2 equal to four times the units of Na_2O, and the subsequent distribution saves a little less than two times the amount of K_2O. With silica still lower it is necessary after making leucite and nephelite, thus saving two times the units of K_2O plus four times the Na_2O, to bring in ackermanite, a device which then saves three fourths of a unit of SiO_2 for every unit of CaO taken from diopside for ackermanite, or one silica on every four converted from wollastonite

ANALYSIS S

SVERIGARE (MELILITE BASALT). *Professional Paper 14*, p. 364, sec. 4, No. 1

Hohenstoffeln, Hegan, Baden

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	Cr_2O_3	H_2O	Sum		
Percentage	35.56	11.25	6.62	6.67	14.68	8.99	3.86	1.75	8.03	2.66	n.d.	100.07		
Molecular Proportions	.593	.110	.041	.093	.367	.177	.062	.019	.100	.018	Salic Minerals		Femic Minerals	Tentative
				18						18			cm 4.0 .018×224	
				75					75				il 11.4	
						25			25				pf 3.4	
			41										hm 6.6	
	76	19						19			lc 8.3			
	124	62					62				ne 17.6			
	58	29				29					an 8.1			
Tentative	(246)			(0)	(123)	(123)								
Tentative	(122)			(0)	(244)									di ol
SiO_2 deficit equals 33	158			0	79	79							di 17.1 { $CaO.SiO_2$ 9.16; $MgO.SiO_2$ 7.900; $FeO.SiO_2$ .00 }	
	144			0	288								ol 20.2 { $2MgO.SiO_2$ 20.16; $2FeO.SiO_2$ .00 }	
	33					44							am 4.4	
											Sal. 34.0		Fem. 67.1	
											Fem. 67.1			
											H_2O			
											Sum	101.1		

into ackermanite. With silica lower still it is necessary to expend as little of it as possible, making nephelite and ackermanite and distributing the silica then remaining between leucite and kaliophilite.

In Analysis S which is calculated like Analysis P, the first of the minor inflexible molecules to be made is chromite (cm), $FeO.Cr_2O_3$, the ratio between FeO and Cr_2O_3 being as 1:1. After ilmenite, which follows, we make perofskite (pf), $CaO.TiO_2$, with $CaO:TiO_2$ as 1:1. If silica has been present in abundance we should have made titanite instead of perofskite. (Cf. Analysis I.)

With the lowest-known ranges of SiO_2, in rocks in which aluminous spinel may form, Al_2O_3 and (MgFe)O being in excess, Al_2O_3 left over after making the feldspars, nephelite, or leucite, is corundum. MgO and FeO uncombined after their allotment to such minerals as magnetite and ilmenite may have to be entered with the femic minerals simply as MgO and FeO. Their percentage weights are determined by multiplying them by the molecular weights of MgO and FeO. Such a case is illustrated in Analysis T.

ANALYSIS T

(MAGNETITE SPINELLITE). *Professional Paper 14*, p. 368, last analysis

Routivaara, Finland

Percentage	SiO_2 4.08	Al_2O_3 0.40	Fe_2O_3 33.43	FeO 34.58	MgO 3.89	CaO 0.65	Na_2O 0.29	K_2O 0.15	TiO_2 14.25	Cr_2O_3 0.20	H_2O 1.32	Sum 99.71	
Molecular Proportions	.068	.063	.210 note	.480	.097	.011	.005	.002	.176	.001	Salic	Minerals	Femic Minerals
				176									il 26.8
	12	2						2	176				
	30	5					5				or 1.1		
	22	11				11					ab 2.6		
		45									an 3.1		
											C 4.6		
			210	210									mt 48.7
					97								MgO 3.9
				94									FeO 6.9
											Sal. 11.4		Fem. 86.3
											Fem. 86.3		
											H_2O 1.32		
												99.02	

NOTE.—Cr_2O_3, .001, has been added to Fe_2O_3.

The student in calculating the analyses given in *Professional Paper 14* should not expect to agree exactly in all cases with the

calculated norms. Where additions as those of small amounts of BaO and SrO to CaO have not been made, slight discrepancies may result all along the line. Numerically the allotment to such minerals as diopside, hypersthene, and olivine may vary by a single unit one way or the other in MgO and FeO. The application of the methods of calculation given in the *Quantitative Classification of Igneous Rocks* should however be precise, the end in view being the correct placing of a given rock where it belongs in the scheme of classification. The method of calculating the norm is necessarily arbitrary in order that concordant results may be obtained by all who make use of it. It should be borne in mind, however, that it agrees with the great body of our observations on the occurrence of minerals in the igneous rocks. The work of calculation has therefore a peculiar value for the student, aside from his needs in classifying rocks, for it directs his thought toward the relations obtaining among the phenomena in cooling rock magmas. It brings home to him why it is that we do not have such an occurrence as that of quartz and nephelite together. It points out to him, for instance, the significance of the presence in a rock of such minerals as corundum, acmite, or perofskite rather than titanite, and it does much to make clear to his mind the significance of each of the mineral molecules occurring in the igneous rocks.

NOTE.—In "The Roman Comagmatic Region," *Publication 57 of the Carnegie Institution of Washington*, Dr. H. S. Washington has stated on p. 15 a modification of the method of calculation proposed by the authors of the quantitative system. This has to do with the normative minerals, sodalite and noselite. These mineral molecules are split up, and in their stead a statement is made in the norm of the amounts of halite (Hl), NaCl, and thenardite (Th), Na_2SO_4. SO_3 takes an equivalent number of molecular units of Na_2O to form thenardite, and Cl takes one-half its number of molecular units of Na_2O to form halite. "The soda which was previously combined with the sodium chloride and sulphate remains with the rest in calculating the norm, and, if necessary, is distributed between albite and nephelite in the usual way. An advantage of this method of procedure is that it minimizes the influence of the small amounts of Cl and SO_3 usually found, which is very great if they bind up in the norm a much greater amount of soda and silica."

THE OCCURRENCE OF A SAUROPOD DINOSAUR IN THE TRINITY CRETACEOUS OF OKLAHOMA

PIERCE LARKIN
Oklahoma Geological Survey

WITH AN INTRODUCTORY NOTE BY S. W. WILLISTON

Recently, during a visit to Norman, Oklahoma, Professor Gould, director of the State Geological Survey, called my attention to a large fossil bone which had lately been discovered in the Trinity Cretaceous of that state by Mr. Pierce Larkin of the survey. This specimen, clearly a morosaurian coracoid, furnishes the first indisputable evidence of the occurrence of the sauropod dinosaurs in the Cretaceous of western America. At my suggestion Mr. Larkin has prepared the following brief description of the Trinity deposits of Oklahoma, giving the precise horizon of the fossil. The precise taxonomic location of the specimen is not possible, since generic characters are not well displayed in the coracoids of the dinosaurs, and because of the partial mutilation of the specimen as it occurred in its matrix. Excellent figures of the specimen, furnished by Professor Gould, will render unnecessary a detailed description of the bone. The occurrence of the Sauropoda in the Lower Cretaceous is of course to be expected, since the recent discovery of similar remains in the Upper Cretaceous of Africa. I have long believed that the Morrison beds of the west are, in part at least, equivalent in age to the Comanche Cretaceous of the interior.—S. W. WILLISTON.

The Trinity division of the Cretaceous of Texas contains three distinct formations, the Travis Peak, the Glen Rose, and the Paluxy. The Travis Peak and Paluxy are sand members, while the Glen Rose is calcareous. Toward the north this formation loses its distinctive characteristics and merges gradually into the sandy members above and below until one part of the Trinity cannot be distinguished from another. Throughout northern Texas and Oklahoma there is practically no change which could be made use of in separating

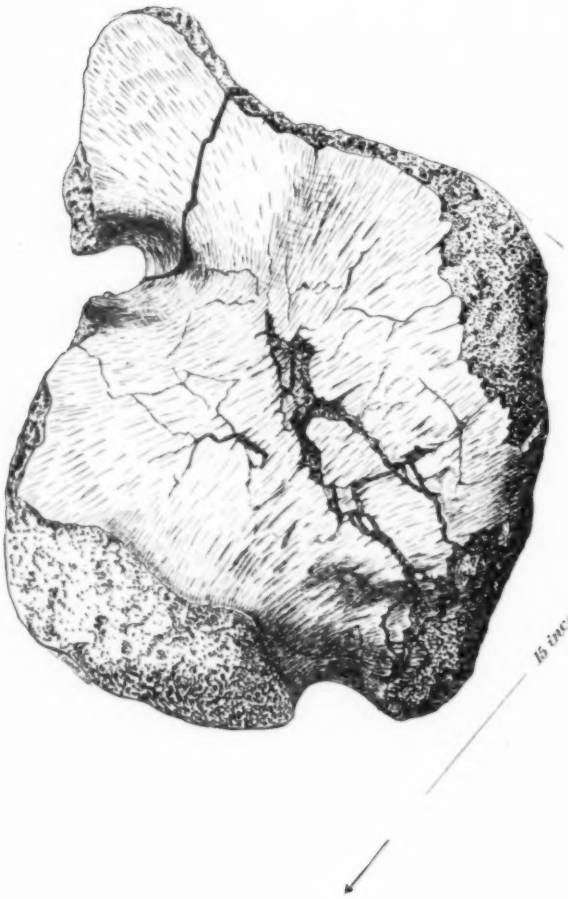


FIG. 1.—Right coracoid of sauropod, external side; one-fourth natural size.

the division into formations. There are no features which are continuous over large areas.

The Trinity enters Oklahoma from Texas near the western

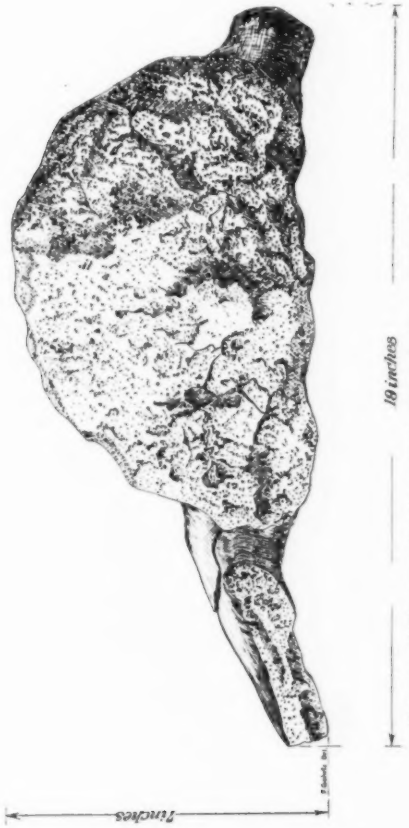


FIG. 2.—Right coracoid of sauropod, upper border; one-fourth natural size.

line of Love County and leaves the state near the center of the McCurtain County line; and is mappable for a considerable distance in Arkansas. In Oklahoma it forms a broad sandy belt of country parallel to the axis of the Ouchita uplift. The average width of the outcrop is about 12 miles, and its length about 200 miles. The

FIG. 3.—Right coracoid of sauropod, lower border; one-fourth natural size.

formation dips under other Cretaceous formations to the south and along Red River forms the reservoir of numerous artesian wells.

The thickness of the Trinity in Oklahoma varies from 200 to 800 feet.

The formation rests unconformably upon granites and Paleozoic rocks. It consists of conglomerates, unindurated or friable sandstones and clays mixed with varying quantities of sand. Most of this material bears evidence of being derived from adjoining rocks which formed the shore of the Cretaceous Sea. The conglomerates especially bear this characteristic. They always occur near the base of the formation and are formed of waterworn bowlders and pebbles of the rocks

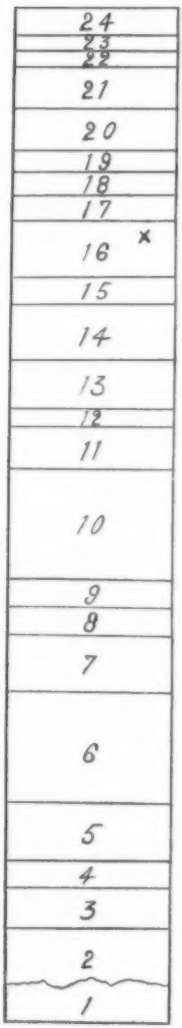
FIG. 4.—Right coracoid of sauropod, posterior border; one-fourth natural size.

upon which they rest, or of a formation near at hand. The sands and clays are not continuous over large areas but consist for the most part of lentils which are cross-bedded and irregularly thrown together. Everything points toward deposition in shallow turbulent water.

A following section across the Trinity along the line of the Missouri, Kansas and Texas Railroad from near Caddo, Oklahoma, to near Atoka, will give the reader some idea of the character of the Trinity at this place, and of the stratigraphic relations of the formations in which the bone was found.

The writer found the fossil dinosaur bone herewith figured in August, 1908, while making an examination of that region under the direction of the Oklahoma Geological Survey.

SECTION ALONG THE M. K. & T. RAILROAD, CADDO TO ATOKA, OKLA.



		FEET
24	Goodland limestone white and massive	20
23	Gray marl	10
22	Yellow cross-bedded sand	12
21	White sand marly in places	30
20	Sand in matrix of yellow clay	30
19	Red and yellow sand with waterworn fragments of gypsum and Ostreae	12
18	Yellow and red arenaceous clay containing clay ironstone concretions	15
17	Yellow clay locally containing lentils of white sand	12
16	White and yellow sand much cross-bedded and containing lentils of yellow sandy clay. It is one of these lentils from which the bone came	40
15	Yellow packsand with lenses of blue arenaceous clay and white sand	20
14	Gray sand in matrix of clay with lentils of brown and red sand. Concretions near the base	40
13	Green gray colored clays containing much sand	34
12	Red sand cross-bedded	12
11	Blue and yellow clay with lentils of yellow and white sand	30
10	The character of these formations could not be determined owing to river deposits	80
9	Gray sandy clay	20
8	Yellow sandy clay	20
7	Yellow clay streaked with red and containing lentils of indurated sandstone	40
6	Valley of South Boggy Creek. The formations covered with alluvium	80
5	Gray sandy clay	40
4	Yellow arenaceous clay with lentils of brown packsand	20
3	Lentils of sand and gravel in beds of gray sandy clay	30
2	Grayish yellow clay with bowlders and lentils of conglomerate	40
1	Atoka formation, Carboniferous shale with lentils of sandstone	00

Reviews

Handbook for Field Geologists. By C. W. Hayes, Ph.D., Chief Geologist U. S. Geological Survey. Pp. 159; 18 figures. New York: John Wiley & Sons, 1909.

This handbook of field methods will be found an important addition to the equipment of the working geologist. The basis of the present book was laid in an earlier volume on geologic field methods issued modestly in a limited edition in 1908 merely for distribution among members of the U. S. Geological Survey, but the frequency with which requests were made for it from members of the state surveys, teachers, mining geologists, and others indicated that a much wider need for such a book was felt, and it was in response to this demand that the present volume has been prepared.

The subject is treated under two main heads—Part I, general instructions, and Part II, instructions for special investigations. Part I covers the more common matters and the more specific instructions to members of the U. S. Geological Survey. Among these are included the field outfit, the more general lines of field observations, and measurements of structural features. These are accompanied by tables and formulas, and by the many graphic and trigonometric aids in solving problems connected with folds, faults, thickness of beds, etc. Upon these subjects much information is given in a condensed form. The taking of notes receives special attention; the purposes and the technique not only of written notes, but of graphic, photographic, traverse, plane table and profile notes, are carefully treated in detail and much attention is devoted to the methods of collecting material for further study and for museum exhibition. The various methods of surveying are also given an important place. The chief emphasis in this part is placed upon the necessity of using sound, accurate, and systematic methods in field work. It is an excellent exposition of the mechanical devices which have been long tried and found serviceable by the Federal Survey and, while doubtless not the last word, may be accepted as the teachings of mature experience.

Part II serves as a guidebook to the significant features to be observed in various special branches of field investigation and in its nature could not be equally complete. Pointers are given for the description and interpretation of land forms, for observations in petrologic and structural geology, for the study of glacial formations, and for the investigation of metalliferous

deposits. These discussions are followed by formal schedules or synopses upon fourteen special topics, such as, e.g., No. 4, Glaciers and glacial deposits; No. 14, Oil and gas. In these the salient features to be noted in the field are arranged in tabular form so as to be suggestive and directive to geologists, especially when working in lines outside their own special fields.

The book closes with an appendix giving a list of the official surveys of the United States, Canada, and Mexico, and the 33 states which conduct such surveys, together with the names of their directors in 1909 and an indication of the extent of their publications.

The booklet, strongly bound in flexible leather, is given a size convenient for use in the field and will be a welcome companion of many a working geologist.

R. T. C.

Geologie der Steinkohlenlager. VON DANNENBERG. Erster Teil, pp. 197, with 25 figures. Berlin: Gebrüder Borntraeger, 1909.

This work is a critical treatise upon the coal-bearing formations of Central Europe in which much attention is given to questions pertaining to the mode of origin of the coal and to the relation between the tectonics of the regions and the character of the coal. The stages in the development of the coals from the original vegetal matter through bacterial action, deformative movements of the strata, and igneous intrusions are carefully treated. Under the head of climatic and atmospheric conditions of the Carboniferous, the author discusses the older hypotheses of a heavy atmosphere, rich in carbon dioxide, and the newer view of an atmosphere with a limited fluctuating carbon dioxide content depending upon many factors. A close relation between extensive coal deposits and periods of unusual vulcanism which might be supposed to furnish the necessary carbon dioxide for the plant growth is sought, but no very apparent relation between the two is found. The Carboniferous was not preceded by any very unusual volcanic activity. To supply the carbon for the Coal Measures one would have to look back to the Devonian igneous activity. But in this discussion the author apparently fails to make use of the fact which he recognizes, namely, that much more carbon dioxide enters into the formation of limestone than is stored away in coal deposits. When it is considered that the atmosphere has been steadily contributing carbon dioxide to extensive limestone development throughout most of the sedimentary geologic history, the storage of carbon in coal beds at certain horizons in the Carboniferous, Cretaceous, Tertiary, etc., becomes less exceptional in its

tax upon the atmosphere and its accessions of gas from vulcanism than it might otherwise seem. The intimate association of glacial deposits with the Permo-Carboniferous coal beds in the comparatively low latitudes of India, South Africa, and Australia furthermore raise the suspicion that some of this vegetal accumulation at least may have taken place at a time when there was only a limited heat-absorbing and heat-retaining blanket of carbon dioxide about the earth.

In the special part is a discussion of the coals of the Carboniferous. This is followed by an excellent description of the salient features of the geology of the various coal districts in Europe in which are included something of the stratigraphy of the beds adjacent to the coal, the tectonics of each region, and the character of the coal developed under these conditions. The details of the geology of these special districts can of course be appreciated better by the European geologist than by those on this side of the Atlantic. They constitute the bulk of the book and appear to have been treated with much care and discrimination. The work is a valuable contribution to the literature of the coal formations.

R. T. C.

A Geologic Reconnaissance of the Island of Mindanao and the Sulu Archipelago. I. Narrative of the Expedition. By WARREN D. SMITH, Chief of Division of Mines. Philippine Jour. of Science, Dec., 1908, pp. 473–99, with 23 plates and 4 figures in the text.

Another instalment of the pioneer field work being done in the Philippine Islands by this active young geologist has come to hand. Up to this time very little has been known of the large southern island of Mindanao, partly because work in other important fields was more urgent and partly because of the hostility of the Moros. This paper gives a brief synopsis of the previous work of a geographic or geologic nature, a general geographic description, notes on the people and climate, and the itinerary and narrative of the expedition. The geologic observations appear with the text of the narrative. An excursion was made to the summit of Mount Apo, which, so far as known, is the highest peak in the Philippine archipelago. Two boiling-point determinations gave it an altitude of 2,956 and 2,902 meters, respectively.

In work of this sort many difficulties were naturally encountered and a military escort was required as a protection against the natives. Upon the basis of this reconnaissance the future detailed studies of this portion of the Philippine archipelago will be planned.

R. T. C.

Geology of the City of New York. By L. P. GRATACAP, A.M. 3d ed., Pp. 232, with 65 figures and 4 maps. New York: Henry Holt & Co., 1909.

The third edition of this work is much enlarged compared with the second, partly through additions of further geological studies of Manhattan Island by various investigators and also by an extension of the geology of Brooklyn and Long Island. It is perhaps because of the fact that this is a revision of an older volume that many antiquated views remain in the text. As an instance, one is struck in reading the introduction by the classification of the Quaternary (p. 8), where it is stated that "the Ice Age has been divided by some geologists (Chamberlin, Salisbury, Leverett) into two epochs—an early and later Ice Age—between which a reforestration of areas made bare and desolate by the ice took place." Such views were indeed held by these geologists twenty years ago, but they long ago recognized their inadequacy and the more complex nature of the Glacial series was described by Chamberlin in the résumé of American Glacial history which appeared in James Geikie's *Ice Age*, in 1895 and has been commonly given in more recent works.

The book describes the rocks of Manhattan Island, such as the gneiss proper, granite, mica schist, hornblende rocks, and limestones, gives their local occurrence and discusses certain problems connected with their origin, metamorphism, etc. There is a list and description of the minerals of Manhattan Island. These are followed by chapters on the Boroughs of Brooklyn, Bronx, and Richmond (Staten Island). The book closes with a chapter on "Evidences of Glaciation in and about Greater New York. The language of the opening pages of this chapter has been taken, as the author remarks in a footnote, from a former paper by himself which appeared in the *Popular Science Monthly* in 1878, and might well have been replaced by fresher matter. The book contains much of local historical and geographical interest. R. T. C.

Bulletin of the Scientific Laboratories of Denison University, Vol. XIV, Articles 6–10, pp. 61–188. Granville, O., April, 1909.

This University Bulletin contains the following articles of geologic interest:

6. Fossils from the Silurian Formations of Tennessee, Indiana, and Kentucky, by Aug. F. Foerste.

8. A Stratigraphic Study of Mary Ann Township, Licking County, Ohio, by Frank Carney.

9. Significance of the Drainage Changes near Granville, Ohio, by Earl R. Scheffel.

10. Age of the Licking Narrows, by K. F. Mather. R. T. C.

College Geology. By THOMAS C. CHAMBERLIN AND ROLLIN D. SALISBURY. Pp. 978, with 21 plates and 608 text figures. New York: Henry Holt and Co., 1909.

This book is essentially an abbreviation of the author's three-volume *Geology*, which appeared in 1904–6, with some changes of matter and mode of treatment and with many new illustrations. R. T. C.

Experimentaluntersuchungen über die auscheidungsfolge von silikaten bei zwei und drei componenten. By R. FREIS. Neues Jahrbuch für Mineralogie. Beilage, Band XXIII, 1907. 47 pp., 13 figs., 3 pls.

Freis gives the results of his studies on the freezing and melting curves, differentiation phenomena, and the sequence of crystallization of the following components:

I. Diopside and anorthite.
II. Diopside and olivine.
III. Diopside and nepheline.
IV. Diopside, anorthite, and magnetite.
V. Diopside, olivine, and magnetite.
VI. Diopside, olivine, and anorthite.
VII. Diopside, olivine, and nepheline.
VIII. Diopside, olivine, and orthoclase.

Various proportions of the chemically pure mineral constituents were melted, and cooled to glass. These glasses were heated in the electric furnace and the following temperatures noted:

T_1. The mass softens and takes slight impressions.
T_2. The mass has become entirely liquid.
T_3. Initial freezing point.
T_4. Freezing completed.

The freezing and melting curves descend to a minimum, lying between the two extremes of composition in the two component systems, indicating the presence of eutectics. Eutectics were also observed in nearly all the three component systems. Undercooling was a marked characteristic of all the freezing curves.

The sequence of crystallization was uniform for all systems, and was independent of the mineral proportions, and eutectics. Eutectic texture was absent. The following was the observed order for all proportions in the respective systems:

I. Diopside, anorthite, diopside.
II. Diopside, olivine.
III. Diopside, nepheline.
IV. Magnetite, diopside, augite, and anorthite.
V. Magnetite, olivine, and augite.
VI. Olivine, diopside, anorthite, and diopside.
VII. Olivine, diopside, and nepheline.
VIII. Olivine, diopside, and orthoclase.

Freis believes that the crystallization sequence followed Rosenbusch's law of increasing acidity of the magma, influenced by undercooling, the force of crystallization, and the solubility law of Nernst.

Differentiation phenomena consisting of local, ill-defined crystal aggregations or schlieren; sharply defined segregations of certain mineral aggregates; local variations in grain; and segregation in the inverse order of specific gravity were observed. Magnetite seemed to be segregated near the top of the melt. Forsterite or iron-free olivine, formed at the bottom, while iron-bearing diopside occupied an intermediate zone.

The order of crystallization and the differentiation phenomena observed by Freis therefore differ in many ways from certain generally accepted theoretical views on magmas.

E. S.